SOME STUDIES ON FLOW MEASURING DEVICES IN OPEN CHANNELS

A Thesis Submitted
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MASTER OF TECHNOLOGY

By
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CERTIFICATE

This is to certify that the thesis titled, "SOME STUDIES ON FLOW MEASURING DEVICES IN OPEN CHANNELS" submitted by Amod Kumar (Roll No. 8910302), in partial fulfilment of the requirements for degree of Master of Technology of the Indian Institute of Technology, Kanpur, is a record of bonafide research work carried out by him under my supervision and guidance. The work embodied in this thesis has not been submitted elsewhere for a degree.

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LIST OF SYMBOLS

a = height of rectangular base weir in proportional weir

b = half of the width of base weir in proportional weir

B = width of control section

C_d = discharge coefficient

C_v = velocity coefficient

F = flexibility

g = acceleration due to gravity

h = head above the base weir

H_1 = upstream head above the crest level of weir

H_2 = downstream head above the crest level of weir

H_{1max} = maximum upstream head above the crest level of weir

H_{2max} = maximum downstream head above the crest level of weir

H_{1min} = minimum upstream head above the crest level of weir

K_s = multiplication factor in Villemonte's generalised equation

m = exponent in Villemonte's generalised equation

M = modular limit

n = exponent in free flow head discharge equation

P = crest height above the base of open channel

Q_f = free flow discharge

Q_s = submerged flow discharge

Q_{max} = maximum discharge

Q_{min} = minimum discharge

Y_{max} = maximum depth of water

Y_{min} = minimum depth of water

δ, λ = Datum parameter.

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ABSTRACT

The present thesis reports studies on two aspects of discharge measurement devices, viz. (i) the selection of flow measurement devices and design and (ii) the measurement of discharge in submerged flow condition. These are reported in part A and part B of the thesis respectively.

The first study reported in part A concerns with relevant devices by considering the constraints and attributes of twenty six open channel flow measuring devices. This is achieved through a database program SELECT, written in FORTRAN IV. For the design of flow measuring devices a program DESIGN is developed. This program uses trial and error procedure to develop the weir geometry.

The second study, reported in part B, is based on an experimental investigation of the submerged flow in six kinds of weir shapes. In the generalised form of Villemonte equation the variation of K_s and m are obtained for all weirs shapes tested. For convenience of discharge prediction two zones of submergence are suggested as follows:

i) Zone I. Where the submergence is 5 to 50 percent

ii) Zone II. Where the submergence is 40 to 95 percent.

The values of K_s and m are obtained for all the weirs, in these two zones. Equations for the prediction of submerged flow discharge with an

accuracy of 97 percent in Zone I and 95 percent in Zone II are obtained. The modular limit at five percent level (M_5) and ten percent level (M_{10}) are also obtained for each of the weirs. These relationships enable submerged flow mode to be used for discharge measurement in sharp crested weirs at an accuracy of about 95%.

PART- A

The selection of flow measurement device and its design

CHAPTER A.1

INTRODUCTION

A.1.1 Introduction

The efficient measurement of discharge in channels is very important for the proper utilization and management of available water resources for irrigation, water supply and waste water disposal etc., so that we can fulfil the objective of available water resources according the demand of users. Also accurate flow measurement is a must for proper charge to be fixed for quantity (volume) of water used or effluent discharged into a stream.

The measurement of discharge in an open channel can be done in two different modes of flow viz. free flow and submerged flow. Both the flow regimes have their own attributes. If the discharge measurement is done in free flow condition, only the upstream head has to be measured. On the contrary, for submerged flow discharge measurement, the measurement of both the upstream and downstream heads above the crest level are necessary.

In the present study two aspects of discharge measuring devices are considered. These are

(i) the selection of flow measurement device and its design

and (ii) the flow measurement under submerged flow condition.

These are described in two parts, viz. in part A and Part B respectively.

In this chapter, the description of the various flow measuring devices commonly used in practice are given.

A.1.2 Principle of flow measuring device

Flow Measuring Devices: The commonly used open channel flow measuring devices are considered under four categories as,

1. broad crested weirs
2. flumes
3. sharp crested weirs

and 4. orifices.

The basic principle of discharge measurement for broad crested weirs and flumes are based on the critical depth theory and their relationship with total energy. To achieve the critical depth in an open channel flow at a geometrically specified constriction is built with the help of broad crested weir and flumes at the crest of broad crested weir and in the throat of flume respectively where sufficient fall is available. Since there is fixed relationship between the specific energy and the critical depth, a single depth in free flow enables the discharge to be estimated in these devices.

In the case of sharp crested weirs and the orifices, the water approaching them with relative low velocity accelerates to high velocity as it issued out from the crest of

a weir or through an orifice. Based on total specific energy, a relationship for the discharge in term of the head over a weir or an orifice is established.

A.1.3 Types of flow measuring device

The commonly used measuring devices in both the categories can be classified into twenty six different categories as below based on the shape and operating characteristic.

1. Broad crested weirs and sills

1.1 Round nose horizontal broad crested weir

1.2 Romjin movable weir (Ref. 1)

1.3 Triangular broad crested weir

1.4 Broad crested rectangular profile weir

1.5 Faiyum weir (Ref. 1)

1.6 Weir sill with rectangular control section

1.7 V-notch weir sill

1.8 Triangular profile two-dimensional weir

1.9 Rectangular profile flat-Vee weir

1.10 Butcher's movable standing wave weir

1.11 WES-standard (ogee) spill way (Ref. 1)

1.12 Cylindrical crested weir (Ref. 1).

2. Flumes

2.1 Long throated flume

2.2 Parshal flume

2.3 H-flume.

2.4 Throatless flume

3. Sharp Crested Weir

3.1 Rectangular sharp crested weir

3.2 V-notch sharp crested weir

3.3 Circular sharp crested weir

3.4 Parabolic sharp crested weir

3.5 Proportional weir.

4. Orifices and Sluice Gate

4.1 Rectangular sharp-edged orifice

4.2 Radial or tainter gate

4.3 Crump-de Gruiter adjustable orifices (Ref. 1)

4.4 Meter gate

4.5 Neyrpic gate (Ref. 1).

Each has a specific range of various characteristics in which it is operational or efficient.

CHARACTERISTICS AND PROBLEMS

A.2.1 Characteristics: The following are the characteristics of a flow measuring device:

(1) The shape of control section perpendicular to flow direction.

(2) Possible functions of a structure.

(3) The minimum and maximum values of upstream head.

(4) The minimum and maximum values of downstream head.

(5) The minimum crest height above the approach channel bed.

(6) The minimum size of control width.

(7) The range of discharge measurement.

(8) The sediment discharge capacity.

(9) Floating and suspended debris passing capacity.

(10) Modular limit.

(xi) Flexibility.

Taking them in detail.

(1) <u>The shape of control section perpendicular to flow direction:</u>

It depends on head and discharge relationship and the maximum and minimum discharge. If variation in the maximum and minimum discharge (i.e. $Y = \frac{Q_{max}}{Q_{min}}$) are high the triangular shape of control section is suitable. If

maximum discharge is less than 0.4 m^3/sec and the sediment and trash are not necessary to be passed then the sharp crested weirs are suitable. Further the shape of sharp crested weir depends on the head discharge relationship. For high discharge above 6 m^3/sec/m the shape is controlled by various practical and constructional reasons. So Ogee spillway or cylindrical crested weirs are suitable for $Q = 6\ m^3/s/m$.

(2) The function of measuring devices:

The measuring devices may have one or more function(s). They are

(a) measurement of discharge without discharge regulation

(b) measurement of discharge with discharge regulation

and (c) the volumetric measurement of discharge.

If the area of control section can not be changed, the structure can only be used to measure discharge without regulation. On the contrary, if the area of control section can be changed with the help of a movable gate arrangement or movable crest level, the measurement of discharge can be done with discharge regulation. The propeller meter (Ref. 1) and the dethridge meter (Ref.1) can measure a flow rate and totalise the volume in cubic meters. In this condition discharge can be regulated

with the help of separate movable gate. So the functional requirement of flow measurement with and without discharge regulation is an important parameter in the selection of relevant discharge measuring devices.

(3) <u>The minimum and the maximum upstream head:</u>

The minimum upstream head, $H_{1\ min}$, and the maximum upstream head $H_{1\ max}$ are very important parameters for the validity of head discharge equation used for any particular measuring devices. The value of discharge coefficient, C_d and velocity coefficient, C_v are also effected by the upstream head. Since each type of measuring device has his own fixed range of head within, which it is operational and efficient. The upstream maximum head is also limited because of various practical and constructional reasons.

(4) <u>The maximum head of downstream:</u>

The maximum downstream head may produce submerged flow condition through a discharge measuring device. The submerged flow behaviour of different measuring devices are different. Some-times the downstream head of measuring device may increase the water level of the upstream and water may over flow through the embankment of channel. It also can produce error in discharge estimation which is mentioned in modular limit.

(5) <u>The minimum crest height above the approach channel:</u>

The constriction is applied with the help of rising the crest level above the bed of channel in a measuring device to obtain required flow situation for their head discharge relationship. Since the required flow situation for flow measurement varies with measuring devices, so the minimum value of crest height above the bottom channel are different for different measuring devices.

For the water supply channel (in irrigation) and for feeding water from main canal to branch canal the minimum water level is also maintained by rising the crest level. To fulfil these requirement, selection of proper value of P and selection of corresponding efficient measuring device is necessary.

(6) <u>Minimum size of control width:</u>

The width of control section controls the upstream head and the discharge in meter^3/sec/meter. It also affect the critical depth in the constriction zone of measuring devices and the water level in the upstream zone. So for a particular situation of open channel flow the judgement of suitable control width with relevant measuring devices are necessary for their efficient operational behaviour.

(7) The range of discharge measurement:

The minimum and maximum discharges are very important characteristics for a measuring device for their efficient operational characteristics. For the maximum discharge the selection also depends on various practical and constructional reasons. Since the minimum discharge effects the minimum head. For each type of measuring device, there is a limiting value of head up to which their head-discharge equation is applicable. For example:

In case of broad crested rectangular profile weir

$H_{1\ max} = 0.6$

$H_{2\ max} = 0.06$ For $P = 1.0m$

$C_{dmax} = 1.0$ $L = 0.5\ m$

$C_{dmin} = 0.84$

where L = length of broad crested weir along the flow direction.

Then,

$$\frac{Q_{1\ max}}{Q_{1\ min}} = Y = \frac{C_{dmax}}{C_{dmin}} \times \left(\frac{H_{1\ max}}{H_{1\ min}}\right)^{1.5}$$

$$Y = \frac{1.0}{0.84} \times \left(\frac{0.6}{0.06}\right)^{1.5} = 37$$

(8) The sediment discharge capacity:

The weir, sill, flumes and tainter gate are efficient discharge measuring structures where the sediments discharge are necessary.

(9) Floating and suspended debris passing capacity:

The sharp crested weir and orifices are easily clogged. So they are not recommended if floating debris has to be passed. The weir with rounded nose and flumes are efficient for passing the floating and suspended debris.

(10) Modular limit:

The modular limit of a given measuring device is defined as the value of submergence ratio H_2/H_1 at which discharge deviates by one percent from the discharge calculated by free flow head discharge relationship. So for a given situation of flow through a channel the ratio of maximum downstream head and upstream head should be considered as important quantity in the selection of discharge measuring devices with reasonable accuracy. A brief review of modular limit is presented in section (B.3.4).

(11) Flexibility:

The flexibility is an important characteristic for flow measuring structures at the junction of main channel and off take channel where flow regulation is necessary to distribute the available discharge between off take channel and main channel according the requirement of available water in a channel. The flexibility of an off take channel measuring device is defined as the ratio of the rate of change of discharge in the off take channel to the rate of change in discharge of the main channel. The flexibility

of an off take channel measuring device is

$$F = \frac{d\, Q_o / Q_o}{d\, Q_m / Q_m}$$

$$= \frac{n_o \; dH_o \; H_m}{n_m \; dH_m \; H_o}$$

since $dH_o = dH_m$

$$F = \frac{n_o \quad H_m}{n_m \quad H_o}$$

$$Q_o = K_o \; H_o^{n_o}$$

where Q_o = discharge passing through off take channel

$$Q_m = K_m \; H_m^{n_m}$$

where Q_m = discharge passing through main channel.

The value of the flexibility may be less than one, equal to one and greater than one. Depending on the value of flexibility a measuring device at the junction of main channel and off take channel, the measuring device may be subproportional, proportional and hyperproportional respectively. By selecting a proper value of the height of crest level and proper category of discharge measuring device the required flexibility of off take measuring device can be obtained and vice-versa. The following example illustrates this point:

Example 1: An irrigation main channel contains an H-flume for discharge measurement. Select a suitable branch channel measuring device having fixed crest at the level of the floor of the H-flume. In this problem the given data are:

$$Y_m = \text{discharge ratio for main channel} = \frac{Q_{max}}{Q_{min}} = 2$$

$$Y_o = \text{discharge ratio for off take channel} = \frac{Q_{max}}{Q_{min}} = \frac{8}{7}$$

Solution: As $$dQ_m/Q_m = \frac{Q_{max} - Q_{min}}{Q_{max}} = \frac{1}{2}$$

$$dQ_o/Q_o = \frac{Q_{max} - Q_{min}}{Q_o} = \frac{1}{8}$$

$$\text{flexibility} = F = \frac{dQ_o/Q_o}{dQ_m/Q_m} = \frac{1}{8} \times \frac{2}{1} = \frac{1}{4}$$

$$F = \frac{n_o \times H_m}{n_m \times H_o},$$

since the crest heights are same ($H_m = H_o$)

As for H-flume $n_m = 2$,

$$F = \frac{n_o}{2} = \frac{1}{4},$$

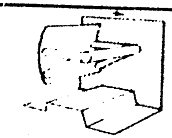
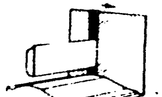
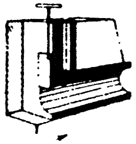
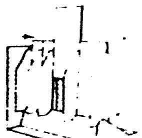
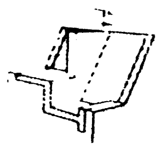
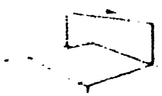
$$n_o = \frac{1}{2}.$$

Hence, a rectangular sharp edge orifice is recommended.

Table A.2.1 gives a summary of the characteristics of the 26 devices used in the present study.

Table A.2.1

Summary of the Characteristics of Different Devices

1	2	3	4	5	6	7	8	10	11	12	13	14
Name of structure and section number in which structure is described	Sketch of structure	Shape of control section perpendicular to flow and u-value	M = measuring MR = measuring & regulating	H_1 min or Δh min	H_1 max or Δh max	minimum crest height above approach channel bottom p	minimum size of control b or B, w and D_p	Q_{min} m^3/s	Q_{max} in m^3/s or q max in m^2/s	$Y = \frac{Q_{max}}{Q_{min}}$	modular limit H_2/H_1 or head loss	debris passing capacity + + very good; □ fair; - poor; - -
Radial or Tainter gate		rectangular u = 0.5	MR	$y_1 \geq 0.15$ m $y_1 \geq 1.25$ w $y_1 \geq 0.1$ r	$y_1 < 1.2$ r	0	$b \geq 0.30$ m $w \geq 0.02$ m	0.005 $y_1 = 0.15$ m	variable	about* 35	variable	-
Crump-de Gruyter adjustable orifice		rectangular u = 0.5	MR	0.03 m 1.58 w	0.60 m	0.20 m p = L	$b \geq 0.20$ m 0.02 m ≤ w ≤ 0.38 m $w \leq 0.63\ h_1$	0.0088	q=0.742	10	up to* 0.25	-
Meter gate		Section of circle u=0.5	MR	$h_1 \geq 1.0\ D_p$ $\Delta h \geq 0.05$ m	$\Delta h \leq 0.45$ m	0.17 D_p	$D_p \geq 0.30$ m $w \leq 0.75\ D_p$ $w \geq 0.02$ m	0.0076 $D_p = 0.30$ m	Q=2.10 $D_p = 1.22$ m	7 to 45	$h_2 \geq 0.15$ m $\Delta H_t \geq 0.30$ r	-
Neyrpic modules		rectangular u = 0.5	MR	$h_d = 0.17$m $h_d = 0.28$m	$h_d \leq p$ and $h_d \leq 0.35\ p_2$	0.16 m 0.26 m	0.05 m 0.05 m	0.0005 0.0010	q=0.100 q=0.200	1* 1	0.60 0.60	- - - -
Weir sill with rectangular control section		rectangular u = 1.5	M	0.09 m 0.75 L	0.90 m 0.5 b	0	0.30 m ≥1.25 b_1	0.013 b=0.30 m	q=1.366	12	0.20	+
V-notch weir sill		triangular u = 2.5	M	$h_1 = 0.03$m	$h_1 = 1.83$ m	[illegible]		0.0001 0.0002 0.0010	Q=25.4** Q=10.6 Q=49.4	50000* 53000 49000	0.30	□
Triangular profile two-dimensional weir		rectangular u = 1.5	M	0.03 m* steel 0.06 m concrete	3.00 m 3.0 p	0.06 m 0.33 H_1	0.30 m 2 H_1	0.0031 $h_1 = 0.03$m 0.0088 b=0.30 m $h_1 = 0.06$m	q=10,18	1000* or 350	0.75	+ +

Continued...

.1 (Continued):

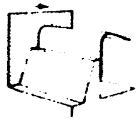
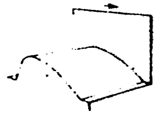
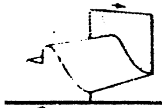
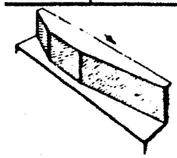
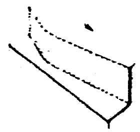
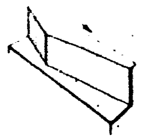
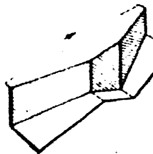
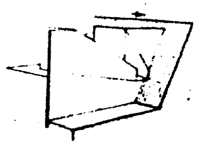
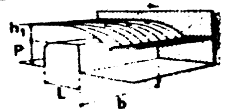
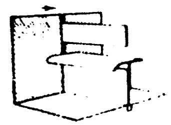
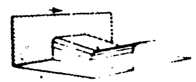
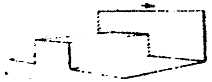
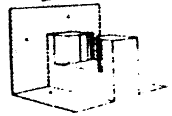
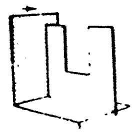
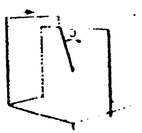
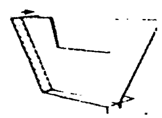
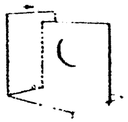
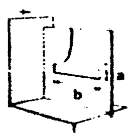
	Sketch of structure	Shape of control section perpendicular to flow and u-value	M = measuring MR = measuring & regulating	H_1 min or Δh min	H_1 max or Δh max	minimum crest height above approach channel bottom p	minimum size of control b or B, w and D_p	Q_{min} m^3/s	Q_{max} in m^3/s or q max in m^2/s	$\gamma = \frac{Q_{max}}{Q_{min}}$	modular limit H_2/H_1 or head loss	debris passing capacity	sediment passing capacity
												++ very good; + good; □ fair; - poor; - - very poor	
		(truncated) triangular u - 1.7 to 2.5	M	0.03 m steel 0.06 m concrete	3.00 m 3.0 p	0.06 m $0.33 H_1$	0.30 m $2 H_1$	0.0137 b=0.03 m 0.0275 h_1=0.06 m b'=0.30 m	depends on degree of truncation	100,000* h_1≥0.03 m 17,500 h_1≥0.06 m	0.67	++	+
		rectangular u = 1.6	MR	0.05 m	1.00 m	$1.4 h_1 max$	0.30 m $2 h_1$	0.0077 b=0.30 m	q=2.30	120	0.70	+	-*
		rectangular u = 1.5	M	0.06 m	depends* on h_d 5.0 p	0.15 m $0.2 h_1$	0.30 m $2 H_1$	0.025 b=1.0 m	variable*	about 1000 but depends on h_d-value	0.30	++	+
		rectangular u = 1.5	MR	0.06 m 0.1 r	depends* on r 3.0 p	0.15 m $0.33 h_1$	0.30 m $2 H_1$	0.0064 b=0.30 m	variable*	about 750, but depends on ratio H_1/r	0.33	++	+
		rectangular u = 1.5	M	0.06 m 0.1 L	1.0 L 1.0 B	0 but Fr≤0.5	0.30 m*	0.0066 b=0.30 m	variable with throat length	35	0.70 to 0.95 depending on downstream transition	++	+
		(truncated) triangular u=1.7 to 2.5	M	for all flumes	for all flumes *Note: in general H_1≤3.0 m*	for all flumes	B≥0.10 m*	0.00098 θ=90°		≤315		++	++
		trapezoidal u=1.6 to 2.4	M				B≥0.30 m*	0.0036 b=0.08 m slope 1:2		≤250		++	++
		parabolic u = 2.0	M				f ≥0.10 m*	0.0027 f=0.10 m		100		++	++
		(semi)-circular u is variable but ≤ 2.0	M				d ≥ 0.20 m*	0.0026 d=0.20 m		100 if d≥0.60 m		++	++
		rectangular u = 1.5	M	0.06 m	2.00 m 1.5 R	0	0.20 m H_1 max	0.0050 b=0.20 m	q=4.8 H_1=2.0 m	190	about* 0.50	++	+
... transition (		rectangular u = 1.5	M	0.06 m	1.80 m	0	0.305 m only	-	-	-	-	++	+
Parshall flumes (22 types)		rectangular u = 1.55	M	0.015 m and 0.03 m	0.21 m to 0.33 m	0 level floor	0.0254 m to 0.0762 m	0.00009 to 0.00077	0.0054 to 0.0321	about 55	0.50	++	+
		u = 1.522 to u = 1.607	M	0.03 m, 0.045 m, and 0.076 m	0.45 m to 0.76 m		0.1524 m to 2.438 m	0.0015 to 0.0972	0.111 to 3,949	about 75	0.60 and 0.70	++	+
		u = 1.60	M	0.09 m	1.07 m to 1.83 m		3.048 m to 15.24 m	0.16 to 0.75 m^3/s	8.28 to 93.04 m^3/s	about 105	0.80	++	+
H-flumes (3 types)		sloping trapezium u = 2.0 to 2.4	M	0.01 m to 0.04 m	0.11 m to 0.30 m	0	see Figure 7.21	0.000012 to 0.00034	0.0003 to 0.022	about 100	0.25	-	□
				0.01 m to 0.03 m	0.14 m to 1.36 m			0.000031 to 0.0014	0.009 to 2.336	about 750	0.25	□	□
								0.0018 and	2.370 and	about 1500	0.30	+	□

Table A.2.1 (Continued):

Name of structure and section number in which structure is described	Sketch of structure	Shape of control section perpendicular to flow and u-value	M = measuring MR = measuring & regulating	H_1 min or Δh min	H_1 max or Δh max	minimum crest height above approach channel bottom p	minimum size of control b or B, r and D_p	Q_{min} m^3/s	Q_{max} in m^3/s or q max in m^2/s	$Y = \frac{Q_{max}}{Q_{min}}$	modular limit H_2/H_1 or head loss	debris passing capacity	sediment passing capacity
												++ very good; + good; □ fair; - poor; - - very poor	
Round-nose horizontal broad-crested weir (4.1)		rectangular u = 1.5	MR	0.06 m 0.05 L	0.5 L	0.15 m 0.33 H_1	0.30 m H_1 max 0.2 L	0.0066 b = 0.30 m	q = 4.7 H_1=2.0 m	35	0.70 to* 0.95	+	□
Romijn movable measuring/regulating weir [illegible]		rectangular u = 1.5	MR	0.05 m 0.12 L	0.78 L	0.15 m 0.33 H_1	0.30 m H_1 max	0.0057* b=0.30 m	Q=0.860* b=1.50 m	30	0.30	+	+
Triangular broad-crested weir		(truncated) triangular u=1.7 to 2.5	MR	0.06 m 0.05 L	0.5 L to 0.7 L	0.15 m 0.33 H_1	0.30 m H_1 max 0.2 L	0.0026 at θ=30°	variable	830*	0.80 to 0.95	+ to □ depending on θ	□
Broad-crested rectangular profile weir		rectangular u = 1.5	MR	0.06 m 0.08 L	0.85 L* 1.50 L	0.15 m if 0.4 h_1 if 0.65 h_1	0.30 m H_1 max 0.2 L	0.0064	q=5.07 H_1=2.0 m	35* 81	0.66 to 0.38	□	□
Faiyum weir ([illegible])		rectangular u = 1.6	M	0.06 m 0.08 L	1.6 L	0.15 m	0.05 m h_1/A_1	0.0011	q=5.1 H_1=2.0 m	90	0.66*	□	-
Rectangular sharp-crested weirs		rectangular u = 1.5	M → or MR →	0.07 m 0.03 m	0.60 m 0.5 b 2.4 p	0.30 m 2 h_1 0.10 m 0.5 h_1	0.30 m B-b>4 h_1 0.15 m	0.00997 0.00137	q=0.813 variable	24.5 if b≥1.2 m about 30	head loss= H_1 +0.05 m head loss= H_1 +0.05 m	- - -	- - - -
V-notch sharp-crested weirs		triangular u = 2.5	M M	0.05 m 0.05 m	0.60 m 1.2 p 0.38 m 0.4 p	0.10 m 0.45 m	H_1 [illegible] h_1 h_1 ≥5.0 h_1	0.0008 about 0.0002 if θ=28°[illegible]	Q=0.390 about Q=0.165 if θ=100°	about 500 about 150	head loss ≥ H_1 head loss ≥ H_1	- - - -	- - - -
Cipoletti weir		trapezoidal u = 1.5	MR	0.06 m	0.60 m	0.30 m 2 h_1	≥0.30 m 1.5 h_1	Q=0.0082 b=0.30 m	q=0.864	36.4	head loss H_1+0.05 m	- -	- -
Circular weir		circular u is variable but ≤ 2.0	M	0.03 m 0.1 d	0.9 d	0.10 m 0.5 d	≥0.20 m	0.00091 d=0.20 m	variable	55.9 if d≥0.30 m	head loss H_1+0.05 m	- -	- -
Proportional weir ( )		proportional u = 1.0	M	0.03 m 2 a	such that x≤0.005 m	p = 0 or p≥0.15 m	0.15 m	0.0058 a=0.006 m b=0.15 m	variable	small, but depends on a-value	head loss H_1+0.05 m	- -	good if p = 0

A.2.2 Factors Affecting Selection of a Device:

The different characteristics of a flow measuring device (as in section A.2.1) are interrelated with one another and these characteristics have their own limitation. So the selection of an ideal flow measuring device for a particular flow situation to fulfill all the functional requirement is difficult. The relevant few structures can be selected by comparing the function requirement with the characteristics of flow measuring devices. The major functional requirements are as follows:

(i) discharge measurement only

(ii) discharge measurement with regulation

(iii) the required head loss

(iv) required upstream and downstream water level

(v) the accuracy in discharge measurement

(vi) required flexibility to fulfill the demand of water according their necessity

(vii) to pass sediment or not

and (viii) to pass trash and floating material.

These requirements can be fulfilled on the basis of the eleven important characteristics of flow measuring devices listed in Section A.2.1. As many as 26 different commonly used measuring devices are considered inthis study. Each one of them has its own attributes and range of characteristics

A very large number of factors influence the selection of proper measuring device. In a practical situation an engineer facing problem of selection of a proper measuring structure, should have proper knowledge of attributes of each type of structure so that he can compare with existing situation and functional requirement. But due to lack of requisite knowledge and systematic analysis of attributes, the probability of a choice of improper or inadequate flow measuring device is indeed large. So the present study deals a method to use the computer to aid in the selection of a set a feasible devices based on a database program for a particular problem. The details of the program along with typical examples are presented in Section A.3.

CHAPTER A.3

SELECTION AND DESIGN

A.3.1 Program: SELECT

The program SELECT is based on database which follow a well defined algorithm that specifies explicitly how to find out variables for any given input variables. The output variables are sorted out step by step on the basis of a given set of input variables. The flow chart showing the various components and functions of the program SELECT is shown in Fig. A.3.1.

The rules of the program is fixed initially on the basis of the following requirements:

(1) Prime function of measuring structure (with or without discharge regulation)

(2) Sediment to be passed or not

(3) The trash and floating material have to be passed or not.

The following input data are required for the selection criteria for discharge measuring devices.

(1) The maximum discharge = Q_{max} in Cumec

(2) The minimum discharge = Q_{min} in Cumec

(3) The maximum depth of water flow = Y_{max} in meters

(4) The minimum depth of water flow = Y_{min} in meters

(5) The width of control section = B in meters

(6) The crest height above the channel bed = P in meters

(7) The required maximum head loss $=\Delta H_{max}$ in meters

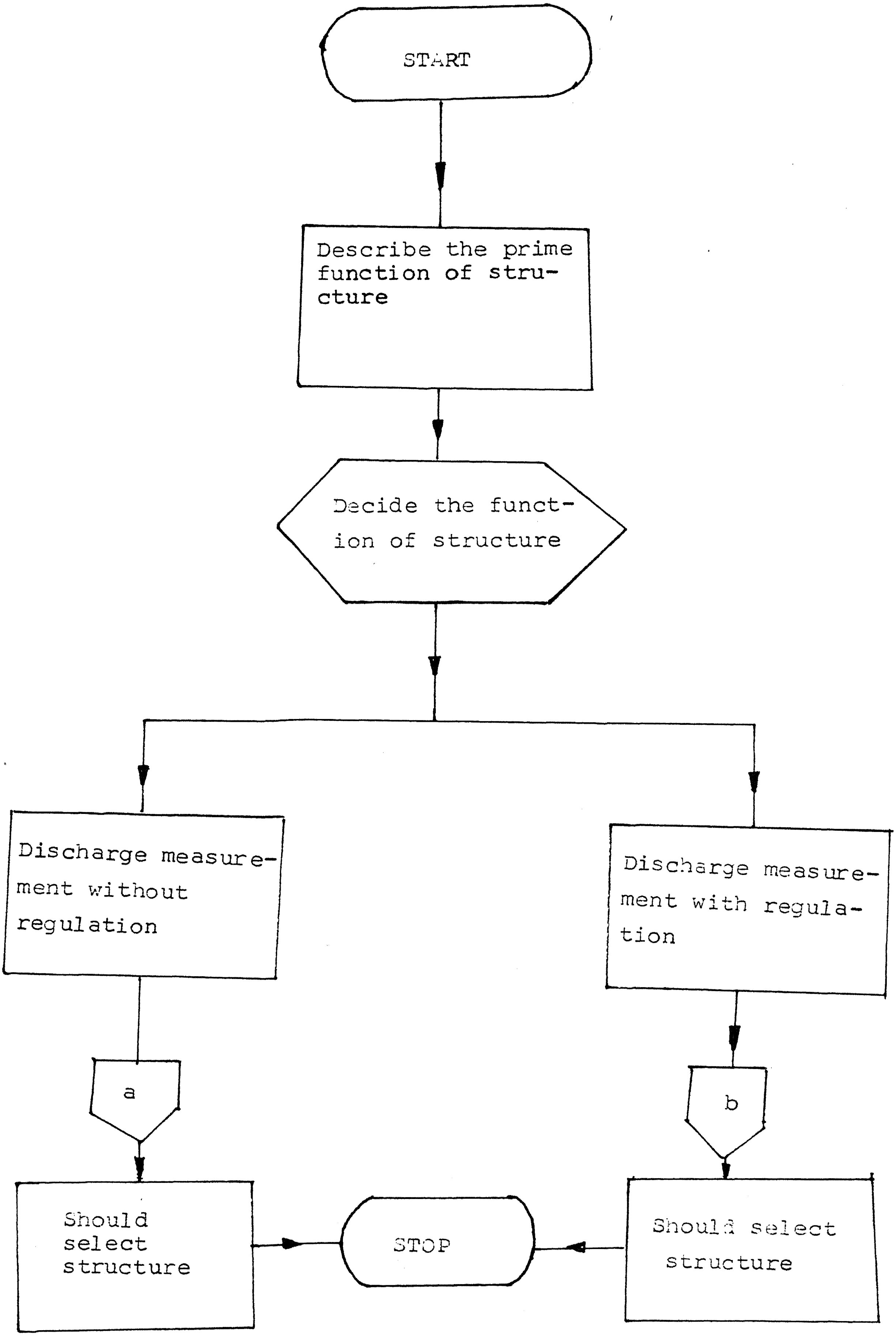
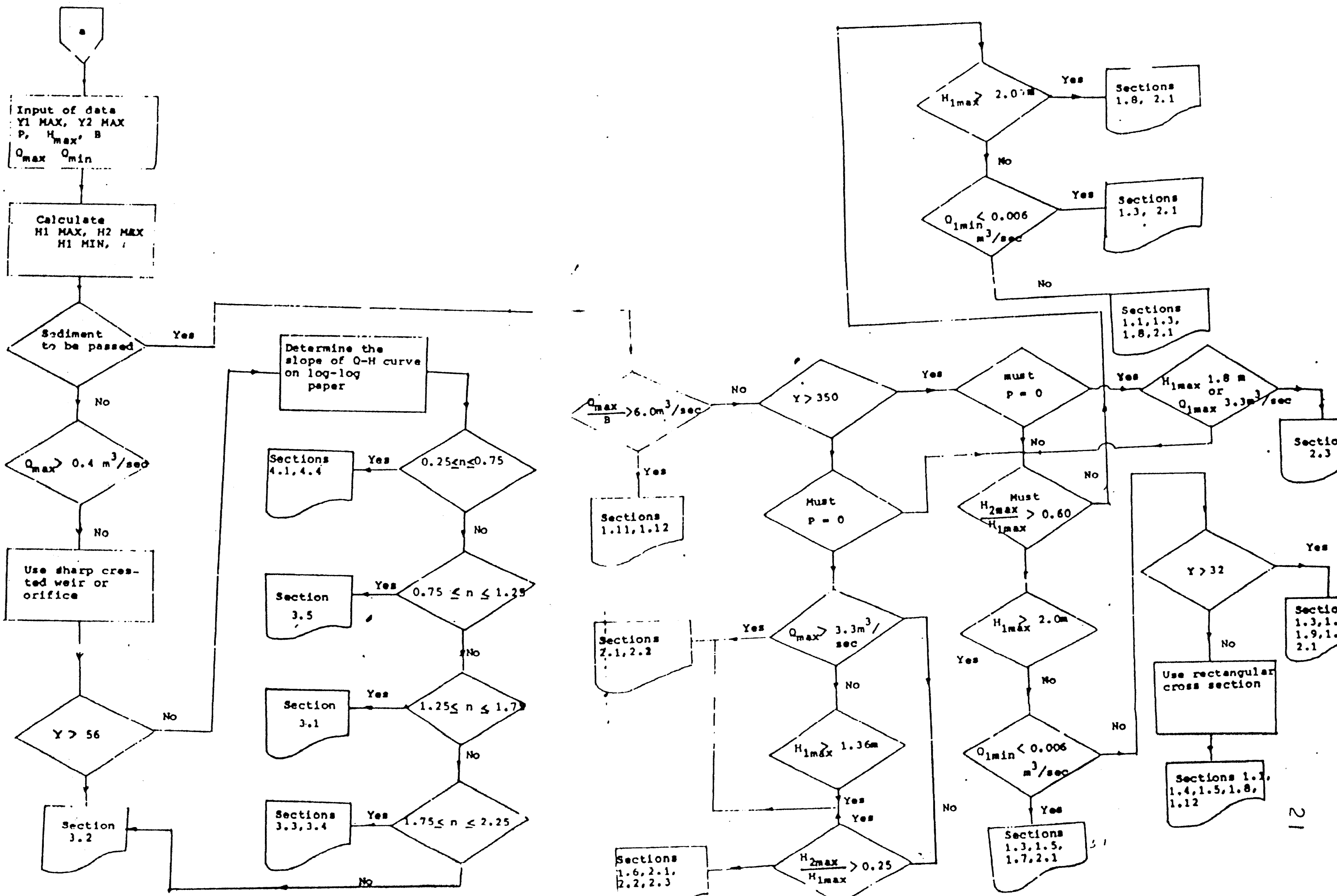


FIG. A.3.1 : Flow chart of program SELECT
Fig.A.3.1.1



Input of data
Y1 MAX, Y2 MAX
P, H_{max}, B
Q_{max} Q_{min}
Calculate
H1 MAX, H2 MAX
H1 MIN,
Sediment to be passed
Yes
No
$Q_{max} > 0.4\ m^3/sec$
No
Use sharp crested weir or orifice
Y > 56
No
Section 3.2
Determine the slope of Q-H curve on log-log paper
$0.25 \leq n \leq 0.75$
Yes
Sections 4.1, 4.4
No
$0.75 \leq n \leq 1.25$
Yes
Section 3.5
No
$1.25 \leq n \leq 1.75$
Yes
Section 3.1
No
$1.75 \leq n \leq 2.25$
Yes
Sections 3.3, 3.4
No
$\frac{Q_{max}}{B} > 6.0 m^3/sec$
Yes
Sections 1.11, 1.12
No
Y > 350
Yes
must P = 0
Must P = 0
$Q_{max} > 3.3 m^3/sec$
Yes
Sections 2.1, 2.2
No
$H_{1max} > 1.36m$
Yes
$\frac{H_{2max}}{H_{1max}} > 0.25$
Sections 1.6, 2.1, 2.2, 2.3
$H_{1max} > 2.0 m$
Yes
Sections 1.8, 2.1
No
$Q_{1min} < 0.006\ m^3/sec$
Yes
Sections 1.3, 2.1
No
Sections 1.1, 1.3, 1.8, 2.1
H_{1max} 1.8 m or Q_{1max} 3.3 m^3/sec
Sections 2.3
Must $\frac{H_{2max}}{H_{1max}} > 0.60$
$H_{1max} > 2.0m$
$Q_{1min} < 0.006\ m^3/sec$
Sections 1.3, 1.5, 1.7, 2.1
Y > 32
Sections 1.3, 1.
1.9, 1.
2.1
Use rectangular cross section
Sections 1.1, 1.4, 1.5, 1.8, 1.12

FIG. A.3.1.2

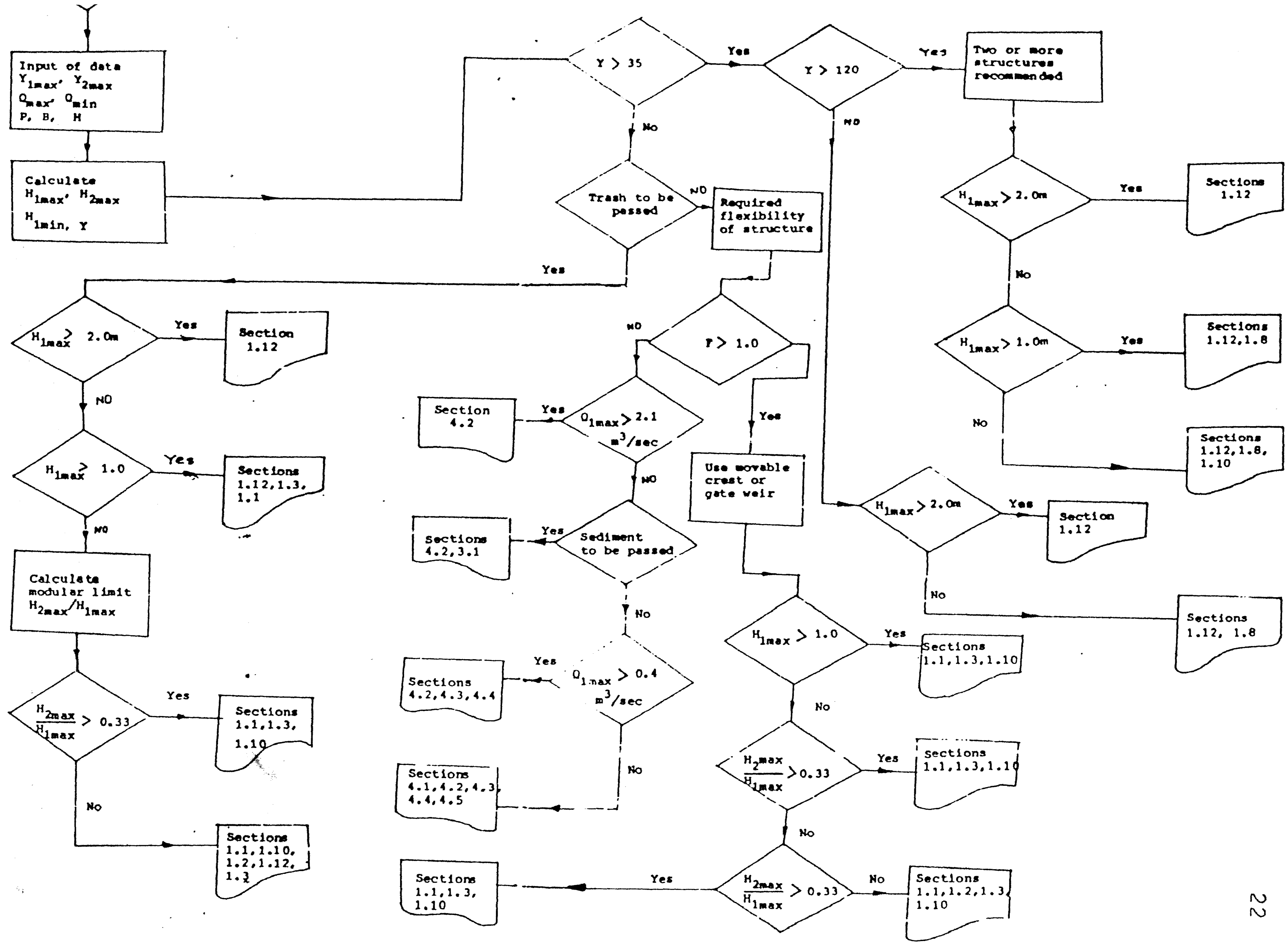

Input of data
Y_{1max}, Y_{2max}
Q_{max}, Q_{min}
P, B, H
Calculate
H_{1max}, H_{2max}
H_{1min}, Y
Y > 35
Yes
No
Y > 120
Yes
NO
Two or more structures recommended
Trash to be passed
NO
Yes
Required flexibility of structure
H_{1max} > 2.0m
Yes
Section 1.12
NO
H_{1max} > 1.0
Yes
Sections 1.12,1.3, 1.1
NO
Calculate modular limit H_{2max}/H_{1max}
$\frac{H_{2max}}{H_{1max}}$ > 0.33
Yes
Sections 1.1,1.3, 1.10
No
Sections 1.1,1.10, 1.2,1.12, 1.3
P > 1.0
NO
Yes
Q_{1max} > 2.1 m^3/sec
Yes
Section 4.2
NO
Sediment to be passed
Yes
Sections 4.2,3.1
No
Q_{1max} > 0.4 m^3/sec
Yes
Sections 4.2,4.3,4.4
No
Sections 4.1,4.2,4.3, 4.4,4.5
Use movable crest or gate weir
H_{1max} > 1.0
Yes
Sections 1.1,1.3,1.10
No
$\frac{H_{2max}}{H_{1max}}$ > 0.33
Yes
Sections 1.1,1.3,1.10
No
$\frac{H_{2max}}{H_{1max}}$ > 0.33
Yes
Sections 1.1,1.3, 1.10
No
Sections 1.1,1.2,1.3, 1.10
H_{1max} > 2.0m
Yes
Sections 1.12
No
H_{1max} > 1.0m
Yes
Sections 1.12,1.8
No
Sections 1.12,1.8, 1.10
H_{1max} > 2.0m
Yes
Section 1.12
No
Sections 1.12, 1.8

FIG. A.3.1.2

and (8) The flexibility of a measuring structure at the junction of two or more channels.

The first four data can be obtained directly by field investigation of an open channel flow. The data (5), (6) and (7) depend on the boundary required to fulfill other objectives. The data (8) is required only when the flow takes place at the junction of two open channels. On the basis of the above data, following parameters are calculated:

(i) Discharge ratio = Y = $\frac{Q_{max}}{Q_{min}}$

(ii) Maximum upstream head = $H_{1\ max}$ in meters

(iii) Minimum upstream head = $H_{1\ min}$

(iv) Maximum downstream head = $H_{2\ max}$

and (v) The exponent of head discharge equation = n.

On the basis of these input values, output values are sorted out step by step and the desired relevant structure(s) is/are obtained.

The program SELECT is given in Appendix AA-1. This program is written in FORTRAN IV. It is simple, efficient and interactive in nature. It can be handled on a personal computer (PC) with small memory.

Typical solution obtained by using program along the respective input is shown in Appendix-AA-2.

It is seen that the program gives a set of possible devices that could be used in a circumstances. The decision

to adopt any one of this set depend upon the case consideration in fabrication and maintenance, environmental and factors peculiar to the fabrication.

A.3.2 Program DESIGN

After selection of the relevant measuring devices their design can be done on the basis of input data by trial and error procedure. Each type of measuring device will have definite head discharge relationship. The actual value of the relevant coefficient of discharge, C_d or the coefficient of velocity C_v, depends on the geometry, the shape and size of a given device and its installation (Refs. 1,3).

Initially trial value of C_d and C_v are assumed and the corresponding value of the heads over the crest are found out. Again the next trial values of C_d and C_v are found out and their corresponding heads are calculated. The process is continued upto desired accuracy of heads above crest level. On the basis of head over the crest the actual required value of crest height is calculated. All the other standard values were calculated, for example (Ref.3). In the case of Ogee spillway having vertical face of upstream spillway the values of the co-ordinates were calculated by equation,

$$\frac{y}{5.31} = 0.50 \left(\frac{x}{5.31}\right)^{1.85} \text{ for downstream profile} \quad (A.3.1)$$

$$\frac{y}{5.31} = 0.724 \left(\frac{x}{5.31} + 0.27\right)^{1.85} - 0.432$$

(x ... 0.625

The computer program DESIGN is developed to provide the basic design of the following type of weirs:

(1) Round nose broad crested weir
(2) Romjin movable measuring/regulating weir
(3) Triangular broad crested weir
(4) Broad crested rectangular profile weir
(5) WES-standard spillway
(6) Linear proportional weir (Ref. 3)
(7) Quadratic weir (Ref. 3)
(8) Logarithmic weir (Ref. 3)
(9) Exponential weir (Ref. 2)
(10) New baseless weir (Ref. 2)

The relevant constraints and the coefficient of discharge of each type of the above weir shape is given in Table A.3.1.

The program is written in FORTRAN IV and given in Appendix AA-3. A few selected design developed by this program along with their respective inputs are shown in Appendix AA-4.

Other Devices: The design of different types of proportional weirs viz. quadratic weir, exponential weir, logarithmic weir and new baseless weir were considered for the design which are not considered in the selection of discharge measuring devices. The consideration of these weirs were done to the complex nature of their profile which is difficult to and time consuming design.

Table A.3.1

Values of coefficient of discharge and constraints

Type of weirs	Discharge equation with coefficient of discharge	Constraints
Round nose broad crested weir	$Q = C_d\ C_v\ \frac{2}{3}\ (\frac{2}{3}\ g)^{1/2}\ B\ H_1^{1.5}$	$H_{1\ min} \gtrsim 0.06$ m or 0.05L
	$C_d = \left[1 - \frac{2x(L-r)}{b}\right]\left[1 - \frac{x(L-r)}{h_1}\right]^{1.5}$	$H_{1\ max}/P \leq 3.0,\ 0.05\ \frac{H_{1\ max}}{L}\ 0$
	C_v = from (Ref. 1, Fig. 1.12)	$P \gtrsim 0.15$ m, $B \gtrsim 0.30$ m or $H_{1\ max}$
Ramjin movable weir (Ref.1)	$Q = C_d\ C_v\ \frac{2}{3}\left[\frac{2}{3}\ g\right]^{1/2}\ B\ H_1^{1.5}$	$H_{1min} \gtrsim 0.05$m or 0.08 L
		$P \gtrsim 0.15$ m or $0.33\ H_{1max}$
		$\frac{H_{1\ max}}{L} \leq 0.75$
Triangular broad crested weir	$H_1 \leq 1.25\ H_L$	Weir angle $\theta > 30^\circ$
	where H_6 = triangular portion height	$H_{1\ min} \gtrsim 0.06$ m or 0.052
	$Q = C_d C_v\ \frac{16}{25}\ (\frac{2}{3}\ g)^{0.5}\ \tan \frac{Q}{2}\ H_1^{2.5}$	$\frac{H_{1\ max}}{P} \leq 3.0,\ P \geq 0.15$
	$H_1 \gtrsim 1.25\ H_L$	$B \geq 0.3$ m, or $H_{1\ max}$
	$Q = C_d\ C_v\ (\frac{2}{3})(\frac{2}{3}\ g)^{0.5}\ B(H_1 - \frac{1}{2}\ H_b)^{1.5}$	
	C_d = and C_v from (Ref.1, Fig.4.10 and 1.12)	

Continued...

Table A.3.1 (Continued):

Type of weirs	Discharge equation with coefficient of discharge	Constraints
4. Broad crested rectangular weir	$Q = C_d\, C_v\, \frac{2}{3} (\frac{2}{3} g)^{0.5}\, B\, H_1^{1.5}$ C_d and C_v are calculated from Ref.1. Fig. 4.14 and 1.12	$H_{1\,min} \geqslant 0.06$ m or $0.08b$ $P \geqslant 0.15$ m, $\frac{H_{1\,max}}{L} \leqslant 1.5$
5. WES standard spillway	$Q = C_e\, \frac{2}{3} (2g)^{0.5}\, B\, H_1^{1.5}$ $C_e = C_o\, C_1\, C_2$, $C_o = 1.3$, $C_2 = 1.0$ for vertical upstream face, C_t from (Ref.1, Fig.6.19)	$\frac{P}{H_{1\,max}} \geqslant 0.2$ $\frac{B}{H_{1\,max}} \geqslant 2.0$
6. Linear proportional weir	$Q = 2\, C_e\, b\, (2ga)^{1/2}\, (h + \frac{2a}{3})$ $C_e = 0.62$	Head measured above the rectangular base weir $h > 0$ $b = B/2$, a = height of base weir
7. Quadratic weir	$Q = 4\, C_e\, ab (\frac{2}{3} g)^{1/2} (h + \frac{a}{3})^{1/2}$	Head measured above the rectangular base weir, $h > 0$, $b = B/2$ a = height of base weir

Continued....

Table A.3.1 (Continued):

Type of weirs	Discharge equation with coefficient of discharge	Constraints
8. Exponential weir	$Q = K\ e^{\lambda h/a}$ $K = \frac{2}{3}\ b\ C_e\ (2g)^{1/2}\ a^{2/3}$ $= \frac{3}{2}\ a$	Head measured above the base weir
9. Logarithmic weir	$Q = K \ln (\sigma + \frac{h}{na})$ $K \ln \sigma = 2b (2g)^{1/2} \frac{2}{3} a^{3/2}$ $\frac{K}{\sigma na} = 2b\ (2g)^{1/2}\ a^{1/2}$	Head measured above the base weir
10. Base less weir NBW-1 NBW-2	$Q = Kh \ln (1 + \frac{h}{T})$ $Q = K\ h^{1/2} \ln (1 + \frac{h}{T})$	

For example the profile equation for exponential weir is

$$x = b\{1 - \frac{2}{\pi} \tan^{-1}(\frac{y}{a})^{1/2}\} + \frac{2K^{3/2} e^{y}}{C_d (2g)^{1/2}} \int_0^y e^{-z^2} dz \qquad (A.3.1)$$

where

$$Q = K e^{-h/a} \qquad (A.3.2)$$

$$K = \frac{2}{3} (2b) C_d (2g)^{1/2} a^{3/2} \qquad (A.3.3)$$

$$\lambda = \frac{3}{2a} \qquad (A.3.4)$$

where λ is datum parameter.

(ii) The logarithmic weir profile

$$x = b\{1 - \frac{2}{\pi} \tan^{-1} (\frac{y}{a})^{1/2}\} - \frac{2}{\pi} \frac{(y/a)^{1/2}}{(6n + y/a)}$$

$$- \frac{6n}{(6n + y/a)^{3/2}} \ln \frac{(6n + y/a) + (y/a)^{1/2}}{(6n + y/a)^{1/2} - (y/a)^{1/2}} \qquad (A.3.5)$$

where,

$$Q = K \ln(6 + \frac{h}{na}) \qquad (A.3.6)$$

$$2b(2g)^{1/2} C_d \frac{2}{3} a^{3/2} = K \ln \qquad (A.3.7)$$

$$2b(2g)^{1/2} C_d a^{1/2} = \frac{K}{6na} \qquad (A.3.8)$$

where b is datum parameter, n is an arbitrary number, a and b are height and half of the width of base weir respectively.

Equations (A.3.7) and (A.3.8) may be used to solve the values of any two of the parameters such as a, σ and b for an assumed value of n. The point of zero width can be shifted by choosing arbitrary higher value of n. So the design of logarithmic weir for maximum and minimum discharges measurement and base width, based on trial and error procedure. These weirs have advantage due to their small relative error.

CHAPTER A-4

CONCLUSIONS AND RECOMMENDATIONS

A.4.1 Conclusions

(1) A data based program (SELECT) has been developed to identify a set of possible measuring devices for a specified set of input data. This program scans 26 devices each having upto ten attributes.

The program SELECT will be of great help to field engineers in identifying an appropriate flow measuring devices in a given open channel flow situation.

(2) A program (DESIGN) has been developed to provide the relevant design parameters along with relevant weir shape profile for ten weir shapes. This program is particularly helpful in the design of different types of proportional weirs viz. exponential weir, new-baseless weir, logarithmic weir etc.

A.4.2 Recommendations

(1) The design of other device shapes listed in program SELECT can be done in the similar fashion. The "star-base" on HP workstation can be used for schematic sketching with detailed design.

(2) A combined interactive program can be developed for the selection as well as for the design of relevant discharge measuring devices.

(3) An expert system should be also developed on the basis of program SELECT.

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PART - B

The flow measurement under submerged flow condition

CHAPTER B.1

INTRODUCTION

B.1.1 Introduction

When water is flowing over the sharp crested weir in such a fashion that the tailwater level is above the crest level of weir then the flow is known as submerged flow. The thin plate weirs are extensively used for the measurement of small discharges due to their accuracy. Normally, these are used in free mode only. If the discharge can be measured with reasonable degree of accuracy (say within five percent of error) in the submerged flow condition also then these devices would have larger range of application. Also, the following advantages of submerged flow can be obtained.

(1) The energy loss occurring through free flow weir will be as great as the energy loss due to considerable length of flow. This loss of energy can be saved considerably with submerged flow mode of discharge measurement.

(2) In free flow the floor of the channel will have to be increased by larger amount above the channel bed there by increasing the silting and seepage loss. But by having submerged flow conditions the silting and seepage loss can be reduced due to reduction in the crest level above the bed of channel.

Surprisingly, the submerged flow over sharp crested weirs, have not received much attention of research workers. Villemonte (1) is probably the first to have conducted a systematic study of submerged flow over weirs. Rangaraju (6) reported submerged flow over broad crested weirs. However, there is no reported work other than that of Villemonte to the best of authors knowledge on submerged flow over thin plate weirs.

A brief review of Villemonte work is given in the next section (B.1.2).

B.1.2 Villemonte's Study

Consider a submerged weir flow as in Fig. B-1, Villemonte assumed that the net flow over the weir could be expressed as the difference of free flow discharge due to head H_1 in upstream minus the free flow discharge due to head H_2 in the downstream.

Thus, if Q_s = submerged flow, Q_{f1} and Q_{f2} are free flow discharged due to head H_1 and H_2 then

$$Q_s = Q_{f1} - Q_{f2} \qquad \text{(B.1.1)}$$

$$\frac{Q_s}{Q_{f1}} = 1 - \frac{Q_{f2}}{Q_{f1}} \qquad \text{(B.1.2)}$$

This assumption implies that the head H_1 and H_2 do not directly affect the flow of water due to head of upstream H_1 above the crest level of the weir and vice versa.

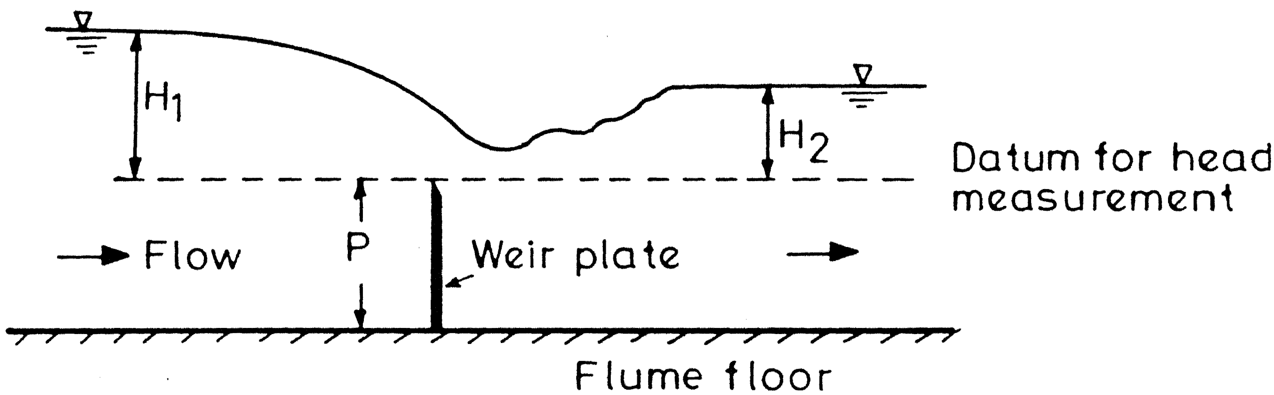

Fig. B.1 Submerged flow weir

The equation (B.1.2) should not be expected to give exact quantitative relationship for determining Q_s, as there are interactions and other perturbing influences which are completely ignored. So the equation (B.1.2) was modified by Villemonte as,

$$\frac{Q_s}{Q_f} = f\left(1 - \frac{Q_{f2}}{Q_{f1}}\right) = K_s \left(1 - \frac{Q_{f2}}{Q_{f1}}\right)^m \qquad (B.1.3)$$

Since,

$$Q_{f1} = C_1 H_1^{n_1}, \quad Q_{f2} = C_2 H_2^{n_2}$$

then

$$\frac{Q_s}{Q_{f1}} = K_s \left(1 - \frac{C_2 H_2^{n_2}}{C_1 H_1^{n_1}}\right) \qquad (B.1.4)$$

where C_1 and C_2, n_1 and n_2 are coefficients and exponents that appear in free-flow discharge equation. For a given type of weir $C_1 = C_2$, $n_1 = n_2 = n$, and taking $Q_{f1} = Q_f$

$$\frac{Q_s}{Q_f} = K_s \left[1 - \left(\frac{H_2}{H_1}\right)^n\right]^m \qquad (B.1.5)$$

In this equation K_s and m are to be found by experiment. Villemonte conducted a large series of experiments in 1943 on seven type of weirs with values of n varying from 1.0 to 3.5. For each weir he assumed $K_s = 1.0$ and mean average value of m was calculated by drawing the best fit line on a logarithmic plot of $1 - \left(\frac{H_2}{H_1}\right)^n$ and $\frac{Q_s}{Q_f}$. He found the exponent m = 0.385 for all the weirs tested.

Thus the discharge equation for all sharp crested weirs was obtained by Villemonte as

$$\frac{Q_s}{Q_f} = \left[1 - \left(\frac{H_2}{H_1}\right)^n \right]^{0.385} \qquad (B.1.6)$$

Further Villemonte recommend the following for practical application of the equation (B.1.6):

(a) Measurement of upstream head H_1 should be done at a distance of at least $4H_1$ from the crest.

(b) Measurement of downstream head H_2 should be done just beyond the surface turbulence caused by the nappe.

(c) (i) For proportional weirs about five percent of accuracy can be expected if $\frac{P}{H_1} > 1.0$,

(ii) For rectangular weir three percent of accuracy can be expected if $\frac{P}{H_1} > 3.0$ and

(iii) For triangular and parabolic weir two percent of accuracy can be expected if $\frac{P}{H_1} > 3.0$.

B.1.3 Comments on Villemonte's Work

The following major comments can be offered on the Villemonte work.

(1) Villemonte used the best fit line, drawn by eye judgement on the logarithmic graph $1 - \left(\frac{H_2}{H_1}\right)^n$ vs. $\frac{Q_2}{Q_1}$ to obtain the value of m = 0.385 and $K_s = 1.0$. The regression analysis of this data indicate slight variation in the value of m as given in Table (B.1.1) and hence the suggested m = 0.385 is only an approximate value.

Table B.1.1

Value of m for $K_s = 1.0$ for Villemonte Data

Sl. No.	Type of weirs	n	m	Percentage deviation from 0.385
1.	Linear proportional weir	1.00	0.368	4.4%
2.	Rectangular weir	1.50	0.370	3.6%
3.	Parabolic weir	2.00	0.390	1.8%
4.	Triangular weir	2.50	0.408	5.9%
5.	Cusp parabolic weir	3.32	0.404	4.9%

(2) The range of the variables used by Villemonte are shown in Table (B.1.2).

Table B.1.2

Range of Variables used by Villemonte's Study

Sl.No.	Type of weirs	n	Head (H_1) in ft	P/H_1	H_r	Q_r	Number of test
1.	Linear proportional weir	1.00	0.206-0.689	>1	0.12-0.831	0.430-0.94	42
2.	Rectangular weir	1.50	0.095-0.310	>3	0.125-0.98	0.448-0.99	59
3.	Parabolic weir	2.00	0.183-0.796	>3	0.138-0.80	0.440-0.890	33
4.	Triangular 90^{o} weir	2.50	0.243-0.555	>3	0.108-0.750	0.405-0.880	40
5.	Cusp parabolic weir	3.32	0.349-0.964	>3	0.112-0.72	0.397-0.800	59

From this it is seen that the range of $\frac{P}{H_1}$ is too restrictive and studies of weir behaviour at lower value of $\frac{P}{H_1}$ is desired.

(3) While from boundary condition $K_s = 1.0$ for $H_2=0$ it is possible that over a wide range of submergence ratio $\frac{H_2}{H_1}$ the equation (B.2.5) may have good correlation with $K_s \neq 1.0$, i.e. $Q_r = K_s \left[1 - \left(\frac{H_2}{H_1}\right)^n\right]^m$. In such a case determination of the best fit m and K_s by regression analysis may give better accuracies.

(4) Villemonte has used only one weir shape in the range $n < 1.5$ viz. linear proportional weir. It is necessary to study the behavior of equation (B.1.5)at more weir shapes with $n < 1.5$. For example, in addition to sutro weir, the behavior of a quadratic weir could also be explored to generalise the use of equation B.5.

B.1.4 The Present Study

While Villemonte equation B.1.6 is extensively quoted in many test books and hand books on fluid mechanics (Ref. 2,4,5,7, 8), it is surprising that there is no other published literature on submerged flow over sharp crested weir. Also, some of the aspects of the flow such as the comments above, need to explored to validate the use of Villemonte equation for a wide range of n-values and $\frac{P}{H_1}$ values. As such an experimental investigation of six different shapes of weirs were done in the hydraulics

laboratory of the Civil Engineering Department, Indian Institute of Technology, Kanpur.

B.1.5 Objective of Present Study

The main objectives of the investigation were:

(1) to study the validity of Villemonte equation (B.1.6) for the range of n from 0.5 to 3.5 and also over a wider range of submergence ratio.

(2) to study the variation of the defined modularity limits as a function of n.

(3) to note other aspects of submerged flow that may affects its use as an adequate flow measuring device.

CHAPTER B.2

EXPERIMENTAL STUDY

B.2.1 Introduction

In the experimental study conducted at Hydraulic Laboratory, Indian Institute of Technology, Kanpur. Six different type of weirs were used in free flow conditions as well as in submerged flow conditions. The weirs were selected in such a fashion that the exponent n in the discharge equation $Q = K H_1^n$ varied from 0.5 to 3.5. For the present study the following weir shapes were used:

		Notional value of n
(1)	Quadratic weir	0.50
(2)	Linear proportional weir	1.00
(3)	Rectangular weir	1.50
(4)	Triangular 90° weir	2.50
(5)	Parabolic weir	2.00
(6)	Cusp parabolic weir	3.34

The photographic views of each of the above weirs are shown in Fig. B.2.1.

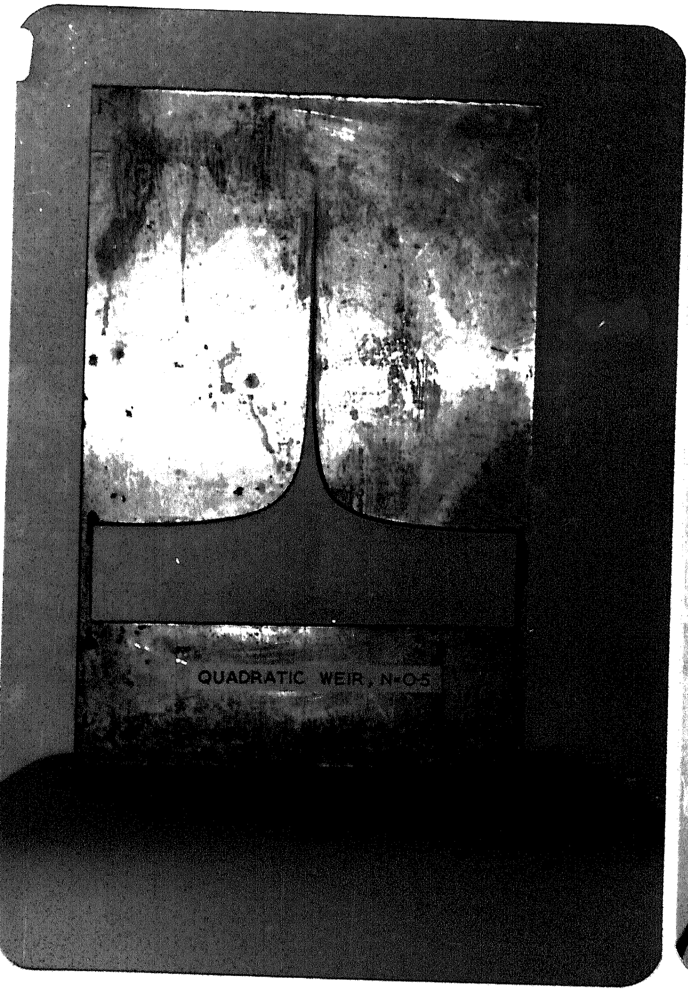

Fig. B.2.1.1

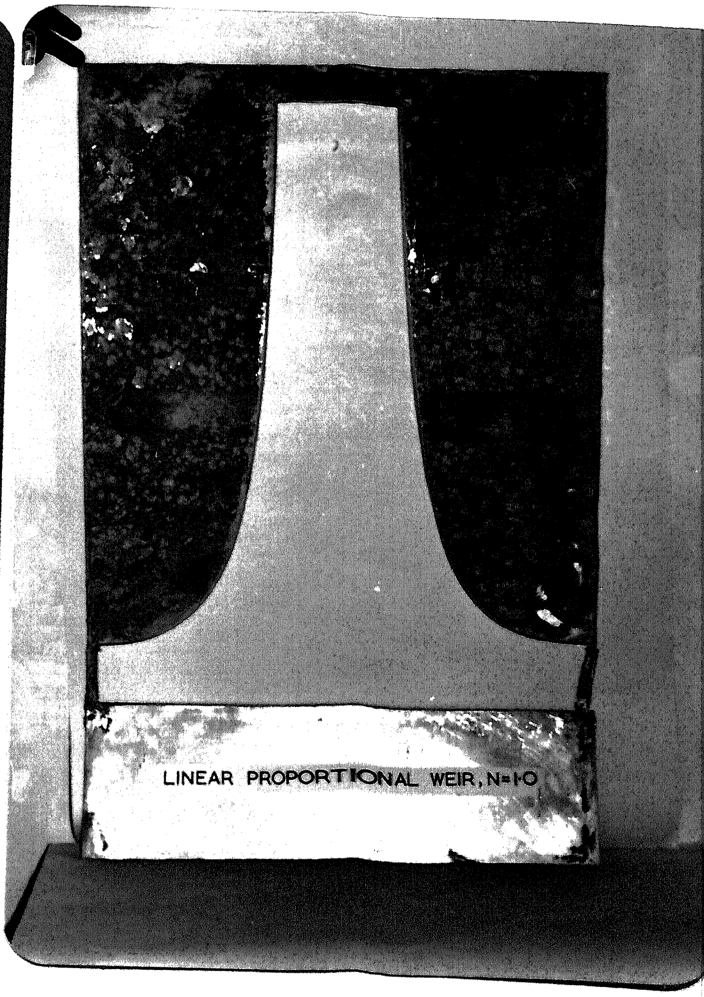

Fig. B.2.1.2

Fig. B.2.1 Photographs of Weirs

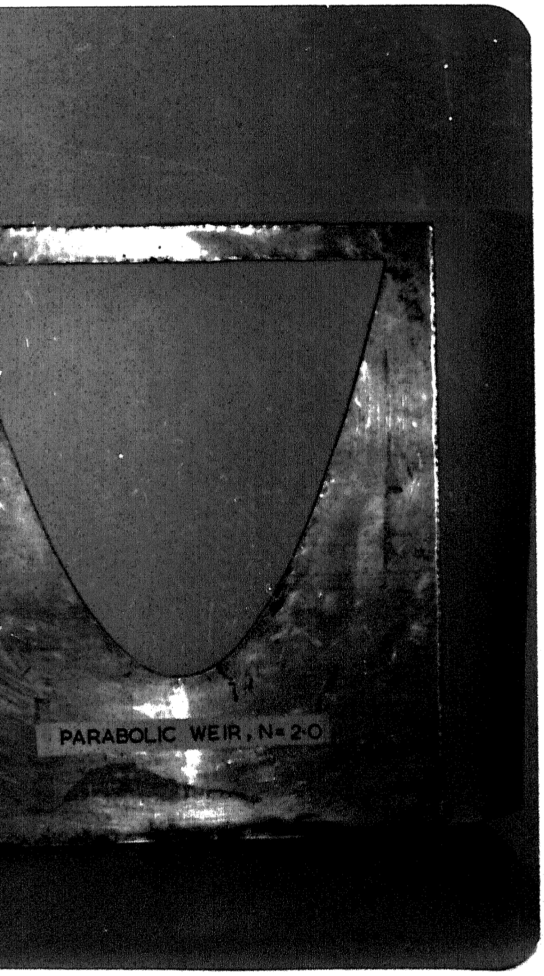

Fig. B.2.1.3

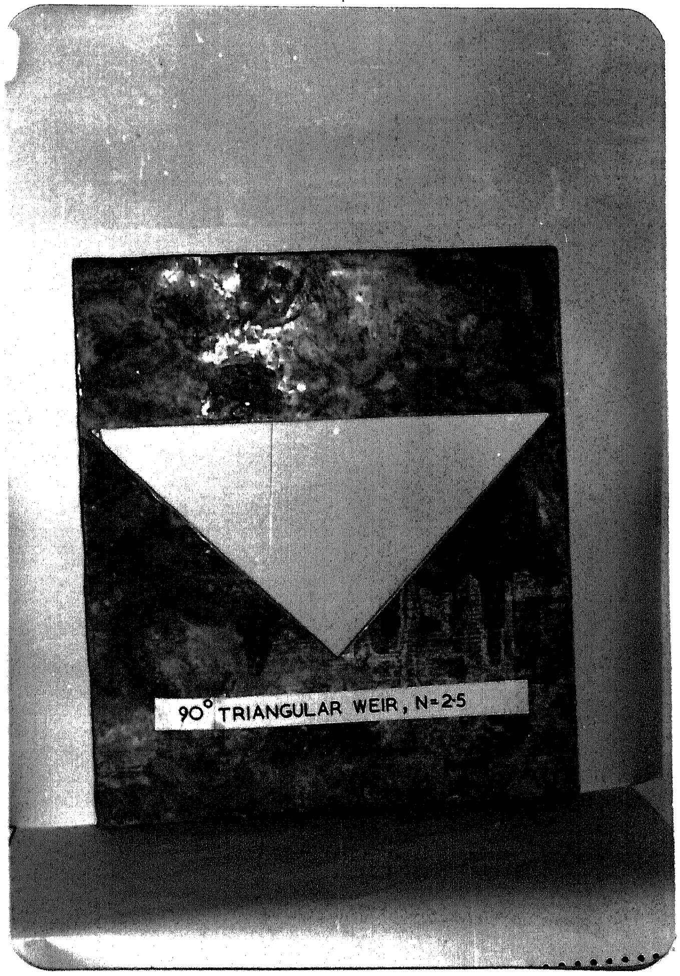

Fig. B.2.1.4

Photograph of Weirs

Photograph of Weirs

B.2.2 Description of Experimental Set-up

Channel: The experiments were conducted in a rectangular flume of length 4.5 m, width 0.45 m and depth 0.9 m. The dimensions and a line sketch of the flume are shown in Fig. B.2.2. The water supply to the flume was from a constant head overhead water tank. A valve in the supply line was used to control the flow. The water from the flume was diverted to sump through a calibrated measuring weir.

Discharge Measurement: The water from the flume was passed through a linear ground level rectangular channel of width 0.48m, which was fitted with a standard rectangular suppressed weir at the end of channel. This weir was well ventilated and carefully calibrated in this study by Volumetric method. The calibration equation of this measurement weir was found to be

$$Q = 1.048\ H^{1.5077} \tag{B.2.1}$$

Q = discharge in m^3 sec, H = head measured at a specific stilling well in meters

This calibration was valid for the range of head from 3 cm to 18 cm. The head on the weir was measured by a point gauge to an accuracy of 0.1 mm.

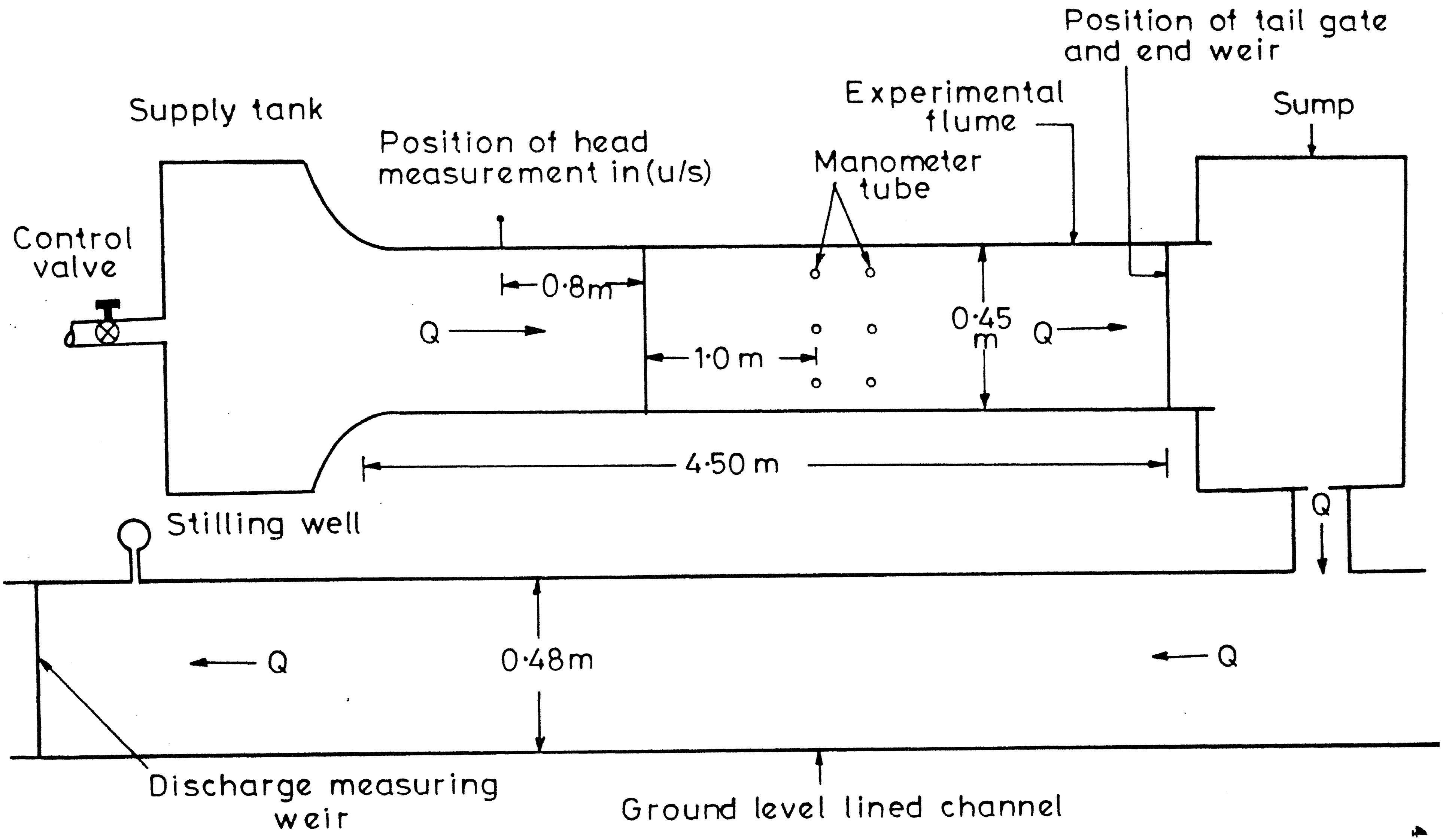

Fig. B.2.2 Schematic sketch of the experimental layout

For a given discharge in the flume the head over the experimental weir as well as head over discharge measuring weir were taken with the help of point gauges. About 25 to 40 sets to readings were taken in the practical range of discharge in the set-up. A total of 185 readings were taken in free-flow studies.

After taking the readings in the free flow condition the weir was placed at a distance of 1.5 m from the supply tank inside the flume for submerged flow discharge studies. For a fixed discharge the desired submergence was produced with the help of the tail gate at the end of flume. The upstream head as well as the downstream head were measured at specified locations. In general a submergence range from five percent to 95 percent was produced and the corresponding head on the upstream and downstream positions were taken. A minimum of three sets of fixed discharge were used. The nature of the nappe in the downstream were also observed for different submergence ratios. About 30 to 45 readings were taken for each type of weir, leading to a total of 225 reading for submerged condition. Basic data, viz., H_1, H_2 and measured discharges are shown in Table B.2.1.

TABLE B.2.1

OBSERVED SUBMERGED FLOW DATA

TABLE B.2.1.1

QUADRATIC WEIR

UPSTREAM HEAD H1(cm)	DOWNSTREAM HEAD H2(cm)	SUBMERGED FLOW DISCHARGE QS(litres/sec)
34.41000	25.80000	47.69910
33.03000	24.40000	47.69910
31.58000	23.30000	47.69910
29.85000	21.80000	47.69910
28.91000	21.20000	47.69910
27.29000	19.50000	47.69910
26.50000	19.00000	47.69910
26.20000	18.60000	47.69910
24.97000	17.70000	47.69910
22.90000	15.76000	47.69910
20.95000	13.25000	47.69910
20.74000	13.20000	47.69910
18.37000	09.48000	47.69910
17.44000	07.10000	47.69910
33.93000	21.66000	57.86529
29.07000	18.00000	57.86529
28.15000	17.20000	57.86529
27.88000	16.60000	57.86529
26.87000	15.60000	57.86529
25.67000	13.60000	57.86529
23.82000	10.00000	57.86529
23.13000	08.00000	57.86529
34.11000	24.10000	50.99486
31.61000	22.00000	50.99486
31.07000	21.70000	50.99486
29.72000	20.80000	50.99486
27.39000	18.90000	50.99486
27.38000	18.80000	50.99486
25.30000	17.20000	50.99486
24.75000	16.80000	50.99486
23.50000	14.80000	50.99486
22.67000	14.10000	50.99486
21.60000	12.36000	50.99486
21.12000	11.60000	50.99486
19.50000	08.60000	50.99486
18.87000	06.90000	50.99486

TABLE B.2.1.2
LINEAR PROPORTIONAL WEIR (n =1.0)

UPSTREAM HEAD H1(cm)	DOWNSTREAM HEAD H2(cm)	SUBMERGED FLOW DISCHARGE QS(litres/sec)
42.49000	38.33000	54.18480
28.08000	20.83000	54.18480
24.58000	15.83000	54.18480
23.54000	14.16000	54.18480
21.39000	10.16000	54.18480
21.12000	09.60000	54.18480
20.08000	07.83000	54.18480
19.90000	04.40000	54.18480
21.64000	10.90000	54.18480
25.99000	18.23000	54.18480
31.18000	24.70000	54.18480
33.90000	28.60000	54.18480
37.96000	33.20000	54.18480
46.92000	43.30000	54.18480
48.27000	40.10000	82.62000
44.44000	35.33000	82.62000
41.03000	31.40000	82.62000
34.60000	20.93000	82.62000
30.12000	10.80000	82.62000
31.12000	13.20000	82.62000
24.70000	21.23000	34.25580
22.54000	18.90000	34.25580
20.75000	16.95000	34.25580
19.19000	14.93000	34.25580
16.83000	11.60000	34.25580
15.64000	09.98000	34.25580
14.35000	07.23000	34.25580
13.38000	04.00000	34.25580
13.82000	05.50000	34.25580
25.70000	20.30000	44.70180
27.72000	23.00000	44.70180
30.06000	24.80000	44.70180
20.33000	13.20000	44.70180
21.62000	14.85000	44.70180
22.86000	16.60000	44.70180
23.72000	17.60000	44.70180
18.15000	08.90000	44.70180
19.20000	11.00000	44.70180
18.87000	06.90000	50.99486

TABLE B.2.1.3
RECTANGULAR WEIR(n=1.5)

UPSTREAM HEAD H1(cm)	DOWNSTREAM HEAD H2(cm)	SUBMERGED FLOW DISCHARGE Q5(litres/sec)
21.25000	18.90000	57.43930
20.40000	17.66000	57.43930
19.17000	15.56000	57.43930
18.97000	15.24000	57.43930
18.76000	14.92000	57.43930
17.98000	13.50000	57.43930
16.55000	09.90000	57.43930
16.31000	08.90000	57.43930
15.86000	07.40000	57.43930
15.76000	07.10000	57.43930
15.33000	05.48000	57.43930
15.09000	04.66000	57.43930
15.00000	04.04000	57.43930
15.41000	05.82000	57.43930
15.59000	06.18000	57.43930
18.61000	16.68000	45.09300
17.89000	15.52000	45.09300
17.20000	14.74000	45.09300
16.60000	13.78000	45.09300
16.30000	13.34000	45.09300
16.20000	13.06000	45.09300
15.98000	12.76000	45.09300
15.47000	11.82000	45.09300
15.44000	11.86000	45.09300
14.71000	10.44000	45.09300
13.79000	07.64000	45.09300
13.35000	05.88000	45.09300
13.02000	04.82000	45.09300
12.86000	04.08000	45.09300
12.62000	02.80000	45.09300
20.19000	18.00000	51.93300
19.20000	16.86000	51.93300
17.45000	14.06000	51.93300
17.16000	13.66000	51.93300
15.58000	09.90000	51.93300
14.95000	07.80000	51.93300
14.63000	07.04000	51.93300
14.48000	06.22000	51.93300
14.35000	05.52000	51.93300
14.23000	04.90000	51.93300
13.97000	04.24000	51.93300
13.91000	03.74000	51.93300
13.84000	03.24000	51.93300
13.80000	03.22000	51.93300
13.62000	01.79000	51.93300

TABLE B.2.1.4
PARABOLIC WEIR

UPSTREAM HEAD H1(cm)	DOWNSTREAM HEAD H2(cm)	SUBMERGED FLOW DISCHARGE QS(litres/sec)
23.45000	12.80000	33.79669
24.09000	15.80000	33.79669
27.70000	23.80000	33.79669
29.88000	26.80000	33.79669
27.53000	23.50000	33.79669
25.37000	17.90000	33.79669
24.05000	15.20000	33.79669
23.74000	13.90000	33.79669
23.00000	10.00000	33.79669
22.83000	07.00000	33.79669
22.73000	04.20000	33.79669
22.68000	01.90000	33.79669
30.67000	23.96000	48.67400
31.82000	26.13000	48.67400
32.99000	28.20000	48.67400
34.93000	31.40000	48.67400
31.55000	26.00000	48.67400
30.24000	23.10000	48.67400
28.00000	18.83000	48.67400
27.71000	14.73000	48.67400
27.62000	14.13000	48.67400
27.58000	13.36000	48.67400
27.35000	10.73000	48.67400
27.10000	08.90000	48.67400
27.02000	06.90000	48.67400
25.98000	15.23000	40.35700
26.19000	16.40000	40.35700
26.50000	17.43000	40.35700
27.25000	19.80000	40.35700
28.65000	23.43000	40.35700
27.17000	19.53000	40.35700
25.81000	15.10000	40.35700
25.14000	11.20000	40.35700
24.95000	09.03000	40.35700
24.81000	06.10000	40.35700

TABLE B.2.1.5
TRIANGULAR 90-DEGREE WEIR

UPSTREAM HEAD H1(cm)	DOWNSTREAM HEAD H2(cm)	SUBMERGED FLOW DISCHARGE Q5(litres/sec)
18.39000	06.17000	20.04980
18.51000	08.17000	20.04980
18.61000	09.37000	20.04980
18.98000	11.53000	20.04980
19.20000	12.81000	20.04980
19.47000	13.95000	20.04980
20.11000	16.03000	20.04980
21.28000	17.59000	20.04980
22.50000	20.55000	20.04980
23.58000	21.85000	20.04980
19.77000	15.27000	20.04980
18.70000	10.58000	20.04980
18.66000	10.13000	20.04980
18.40000	07.29000	20.04980
18.33000	05.65000	20.04980
18.[illegible]5000	02.81000	20.04980
19.42000	07.59000	23.02300
19.34000	06.09000	23.02300
19.28000	04.31000	23.02300
19.32000	04.93000	23.02300
19.36000	05.71000	23.02300
19.40000	06.67000	23.02300
19.47000	08.25000	23.02300
19.54000	09.31000	23.02300
20.18000	13.11000	23.02300
20.42000	14.15000	23.02300
20.97000	16.09000	23.02300
22.17000	18.97000	23.02300
23.22000	20.87000	23.02300
21.10000	16.83000	23.02300
21.06000	16.69000	23.02300

TABLE B.2.1.6
CUSP PARABOLIC WEIR(n=3.4)

UPSTREAM HEAD H1(cm)	DOWNSTREAM HEAD H2(cm)	SUBMERGED FLOW DISCHARGE QS(litres/sec)
20.66000	02.32000	15.34790
20.67000	06.52000	15.34790
21.07000	12.52000	15.34790
22.36000	18.62000	15.34790
20.68000	05.32000	15.34790
20.78000	09.12000	15.34790
20.82000	07.92000	15.34790
21.03000	12.32000	15.34790
21.10000	13.02000	15.34790
21.67000	16.02000	15.34790
22.00000	16.52000	15.34790
23.70000	20.52000	15.34790
21.68000	16.52000	15.34790
20.84000	07.52000	15.34790
21.41000	15.22000	15.34790
19.52000	06.72000	15.34790
19.67000	09.62000	12.51725
21.16000	17.62000	12.51725
21.50000	18.42000	12.51725
22.98000	21.32000	12.51725
19.91000	12.22000	12.51725
19.89000	12.02000	12.51725
20.98000	16.12000	12.51725
21.20000	18.72000	12.51725
19.85000	11.72000	12.51725

Weirs: The weirs used for the study were prepared from 3 mm thin aluminium plate by cutting and filling according to specified dimensions. The standard requirement of the sharp crested weirs were considered in the preparation of the plate. Fig.B.2.3 shows the details of the various weir shapes used.

The experiments were conducted on the six different type of weirs in both free flow conditions as well as in submerged flow modes.

Head Measurement: The head over the experimental weir in the flume was measured with the help of a point gauge fitted with Vernier of least count 0.1 mm. The head on the downstream of this weir in submerged condition was measured with the help of six piezometer tapping placed in the downstream portion of the weir as shown in Fig. (B.2.2) and connected to a bank of manometers. The water manometer reading were taken to an accuracy of 0.2 mm.

B.2.3 Experimental Procedure

Experimental Procedure: For free flow and submerged flow conditions the weir under study was first placed at the end of flume. The flow from the weir had a free over flow ensuring full aeration and free flow mode for all discharges. For free flow studies, the flow in the flume was controlled by a valve in the supply line. The head on the weir was measured at a distance of about four times the upstream head after the flow was stabilised.

$$X = 6\left\{1 - \frac{2}{\pi}\tan^{-1}\sqrt{\frac{y}{a}}\right\} - \frac{6}{\pi}\frac{\sqrt{y/a}}{(1+\frac{3y}{a})}$$

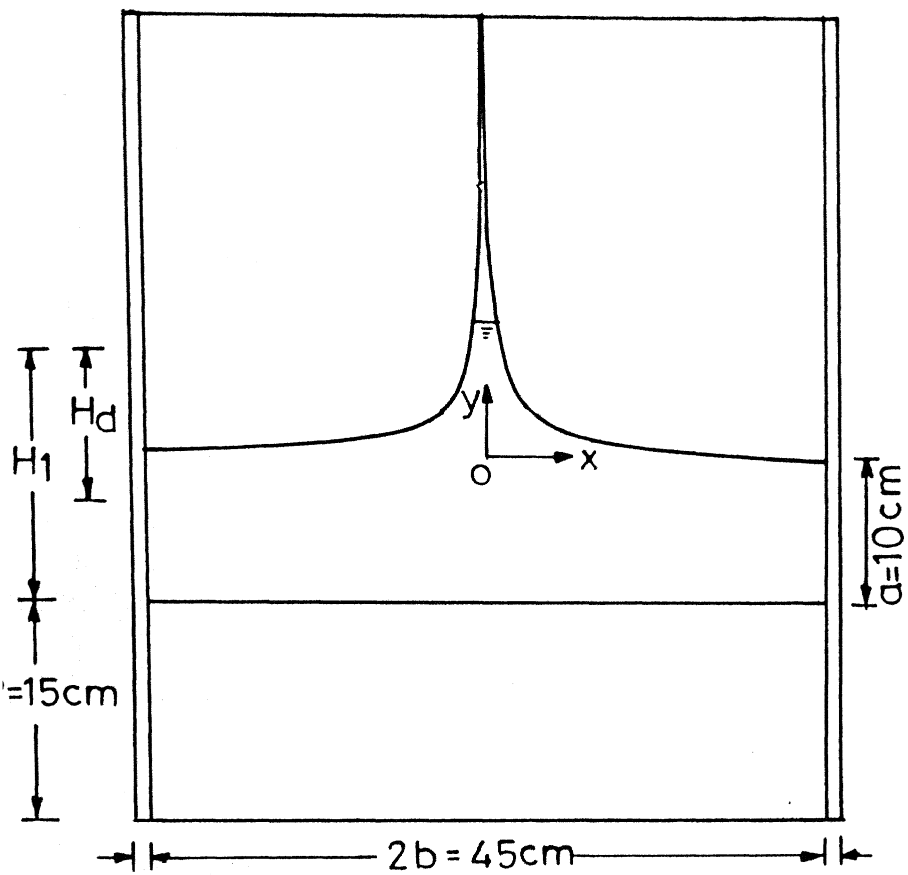

Fig. B.2.3.1 Quadratic weir
(n=0·5)

$$X = b\left\{1 - \frac{2}{\pi}\tan^{-1}\sqrt{y/a}\right\}$$

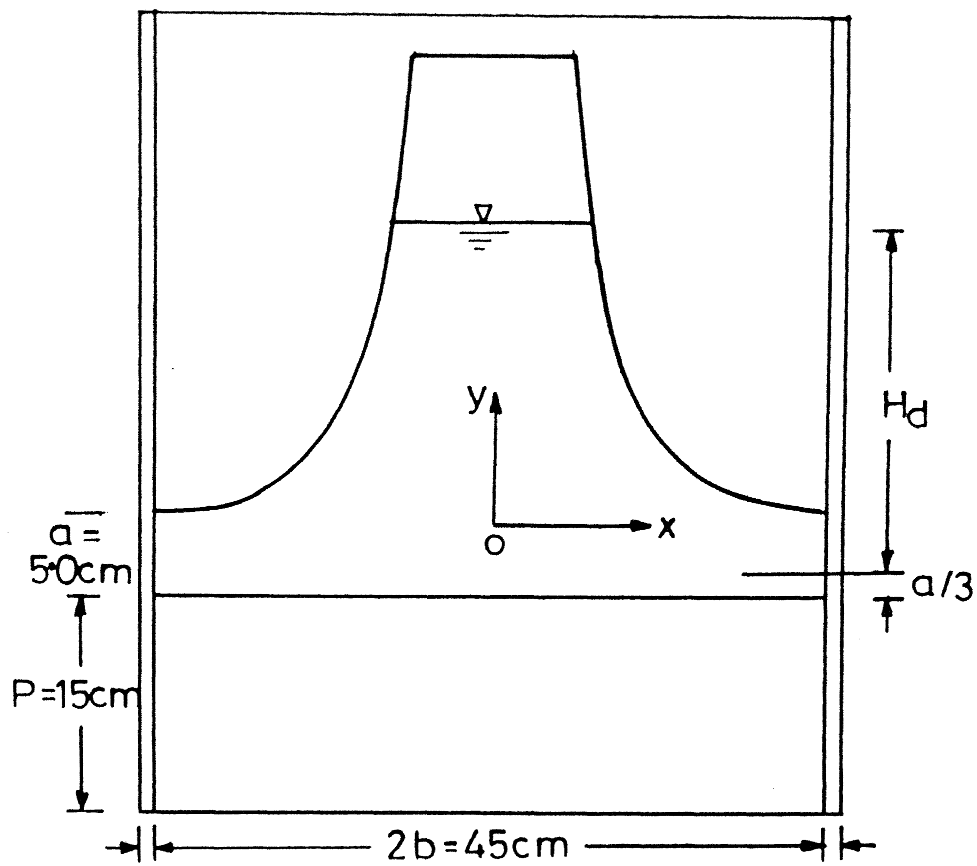

Fig. 2.3.2 Linear proportional weir
(n=1·0)

FIG. 2.3

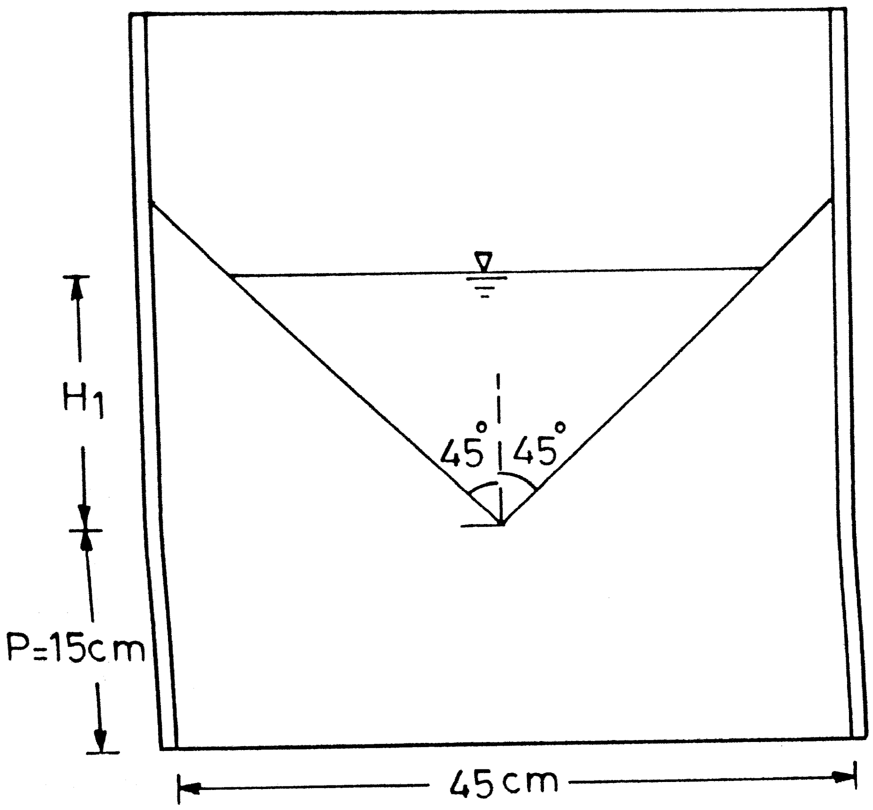

Fig. B.2.3.5 90 Triangular (n=2·5)

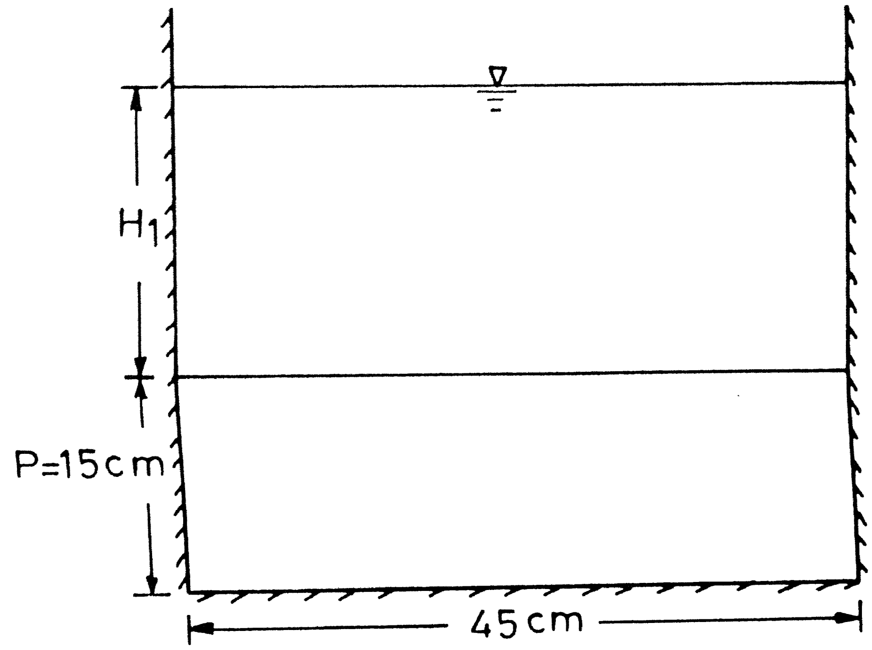

Fig.B.2.33 Rectangular suppressed weir (n=1·5)

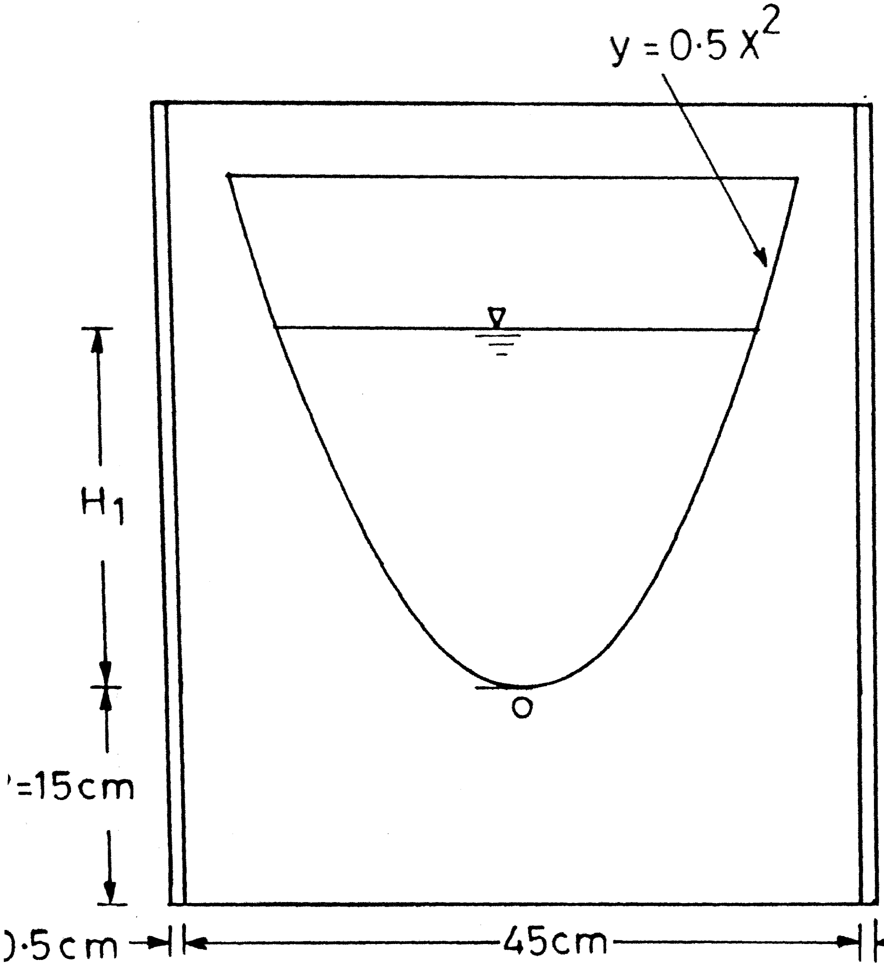

Fig. B.2.3.4 Parabolic weir
(n=2·0)

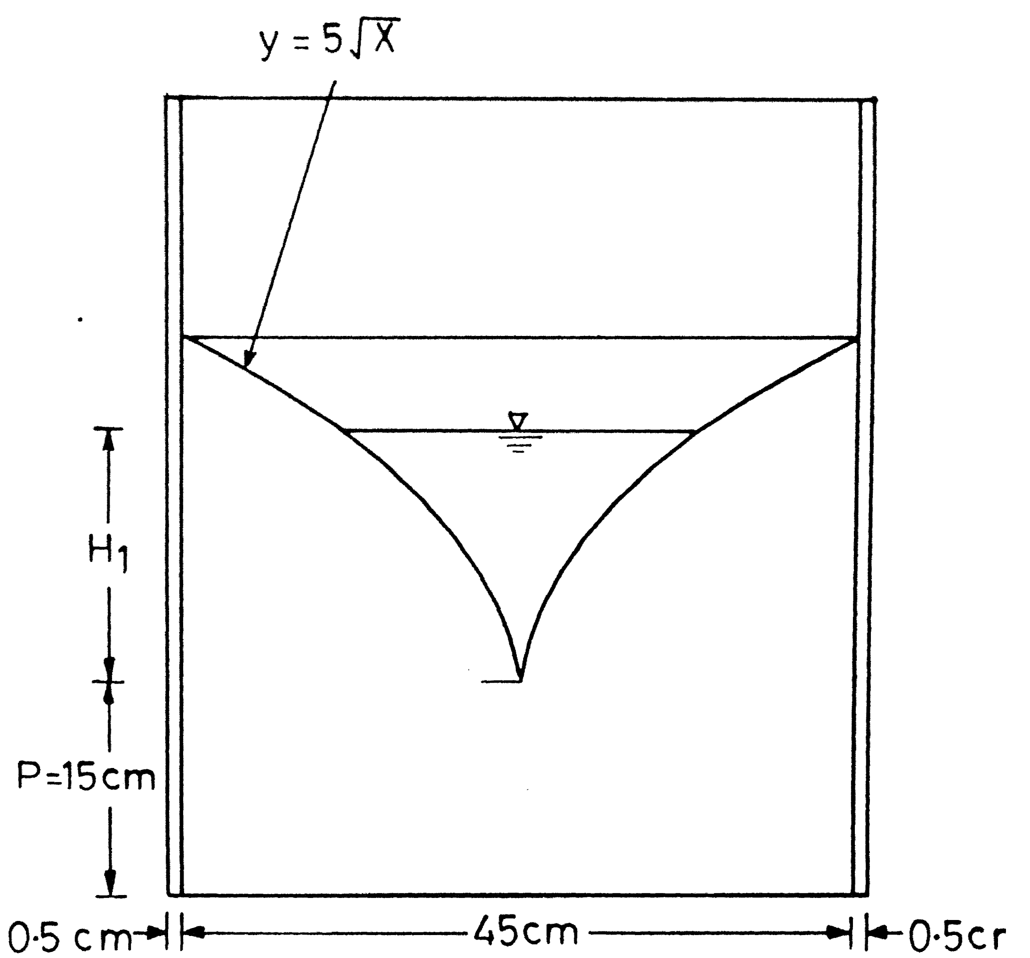

Fig. B2.3.6 Cusp-parabolic weir
(n=3·4)

B.2.4 Study of nappe: The nature of the nappe in the submerged flow was observed for all the weir shapes. It was found that the nappe could be classified into two types, viz. (i) plunging nappe, (ii) and the surface nappe.

In a plunging nappe the water surface plunges into the downstream flow creating a depression of water surface in the intermediate neighbourhood of the weir (Fig.(B.3.4)). In contrast, the water surface in the surface nappe is smooth and there is no appreciable depression of the water surface on the downstream side (Fig. (B.3.5)).

The plunging nappe was observed at low submergences (H_2/H_1 of about 0.40) for rectangular, parabolic, 90^o triangular and the cusp parabolic weir. However, for proportional weir and quadratic weir, there was no plunging nappe for all the submergence values of H_2/H_1 when the water surface was above the rectangular base weir. For high submergence ratio the surface nappe was observed in all weir shapes. The transition from plunging to surface nappe occurred at approximately a value of $(H_2/H_1)_t$ as given below:

Sl.No.	Type of Weirs	n	Transition $(H_2/H_1)_t$
1.	Quadratic weir	0.50	0.00
2.	Linear proportional weir	1.00	0.00
3.	Rectangular weir	1.50	0.35
4.	Parabolic weir	2.00	0.55
5.	Triangular 90^o-weir	2.50	0.60
6.	Cusp parabolic weir	3.40	0.65

In a plunging nappe, the oscillation of water surface in form of crest and trough was observed. The oscillating waves were found stabilised in the downstream at about four to five times of Head H_1. However, in suppressed rectangular weir, $n = 1.5$ the oscillating water surface was stablised only at larger distance of about 8 H_1. This is probably due to absence of lateral expansion of the downstream flow in the weir.

CHAPTER B.3

RESULTS AND DISCUSSIONS

B.3.1 Analysis of Experimental Data:

The free flow discharge equation for different type of weirs were found by regression analysis between upstream head H_1 above the crest level of weir and the measured discharge Q_f in the equation.

(1) $$Q_f = K \; H_1^n \qquad (B.3.1)$$

for the rectangular, parabolic, 90^o-triangular and cusp parabolic weirs.

(2) $$Q_f = K \; (H_1 - \frac{2a}{3})^n \qquad (B.3.2)$$

for the quadratic weir.

(3) $$Q_f = K \; (H_1 - \frac{a}{3})^n \qquad (B.3.3)$$

for the linear proportional weir,

where a = depth of the rectangular base weir in meter, H_1 = head above the crest of weir on the upstream in meter and Q_f = measured discharge in m^3/sec.
The actual value of K and n obtained by the regression analysis of the free flow data are shown in Table (B.3.1).

Table (B.3.1)

Free Flow Discharge Equation of Weirs by Calibration

Sl.No.	Type of weirs	Equation	K	n	Coefficient of corre-lation	Coefficien of standar error
1.	Quadratic weir	$Q_f = 0.14033(H_1 - \frac{2a}{3})^{0.4685}$	0.14033	0.4683	0.9978	0.00672
2.	Linear propor-tional weir	$Q_f = 0.27315(H_1 - \frac{a}{3})^{0.9625}$	0.27315	0.9625	0.9997	0.00516
3.	Rectangular weir	$Q_f = 1.0863\ (H_1)^{1.5077}$	1.0863	1.0863	0.9997	0.00628
4.	Parabolic weir	$Q_f = 0.771\ H_1^{2.087}$	0.771	2.087	0.9805	0.061
5.	90^o Triangular weir	$Q_f = 1.7938\ H_1^{2.637}$	1.7938	1.7938	0.9981	0.0316
6.	Cusp parabolic	$Q_f = 3.4075\ H_1^{3.4281}$	3.4075	3.4075	0.9891	0.0723

In submerged flow of a weir with head H_1 and H_2 on the upstream and downstream respectively, the hypothetical free flow discharge to any upstream head H_1 was calculated as follows. The equations used were

(1) $$Q_f = K \cdot H_1^n \qquad (B.3.1)$$

for rectangular, parabolic, 90^o-triangular and cusp parabolic weirs

(2) $$Q_f = K\,(H_1 - \frac{2a}{3})^n \qquad (B.3.2)$$

for quadratic weir and

(3) $$Q_f = K(H_1 - \frac{a}{3})^n \qquad (B.3.3)$$

for linear proportional weir. The proper values of K and n were taken from Table (B.3.1). The submerged free flow discharge Q_s for each set of upstream head H_1 and down stream head H_2 was known from discharge measurement. Fig. (B.3.1) show the variation of $\frac{Q_s}{Q_f}$ against H_2/H_1 for all the weir shapes. It is seen that for each weir shape the submerged flow discharge decreases, i.e. Q_s/Q_f decreases with an increase of H_2/H_1. Detail explanation of this is given in the next section (B.3.4)

Defining $Q_r = \frac{Q_s}{Q_f}$, $H_r = 1 - (H_2/H_1)^n$ the discharge ratio as in the form of generalised Villemonte equation

$$Q_s/Q_f = K_s\,[1 - (\frac{H_2}{H_1})^n]^m \qquad (B.1.5)$$

can be written as

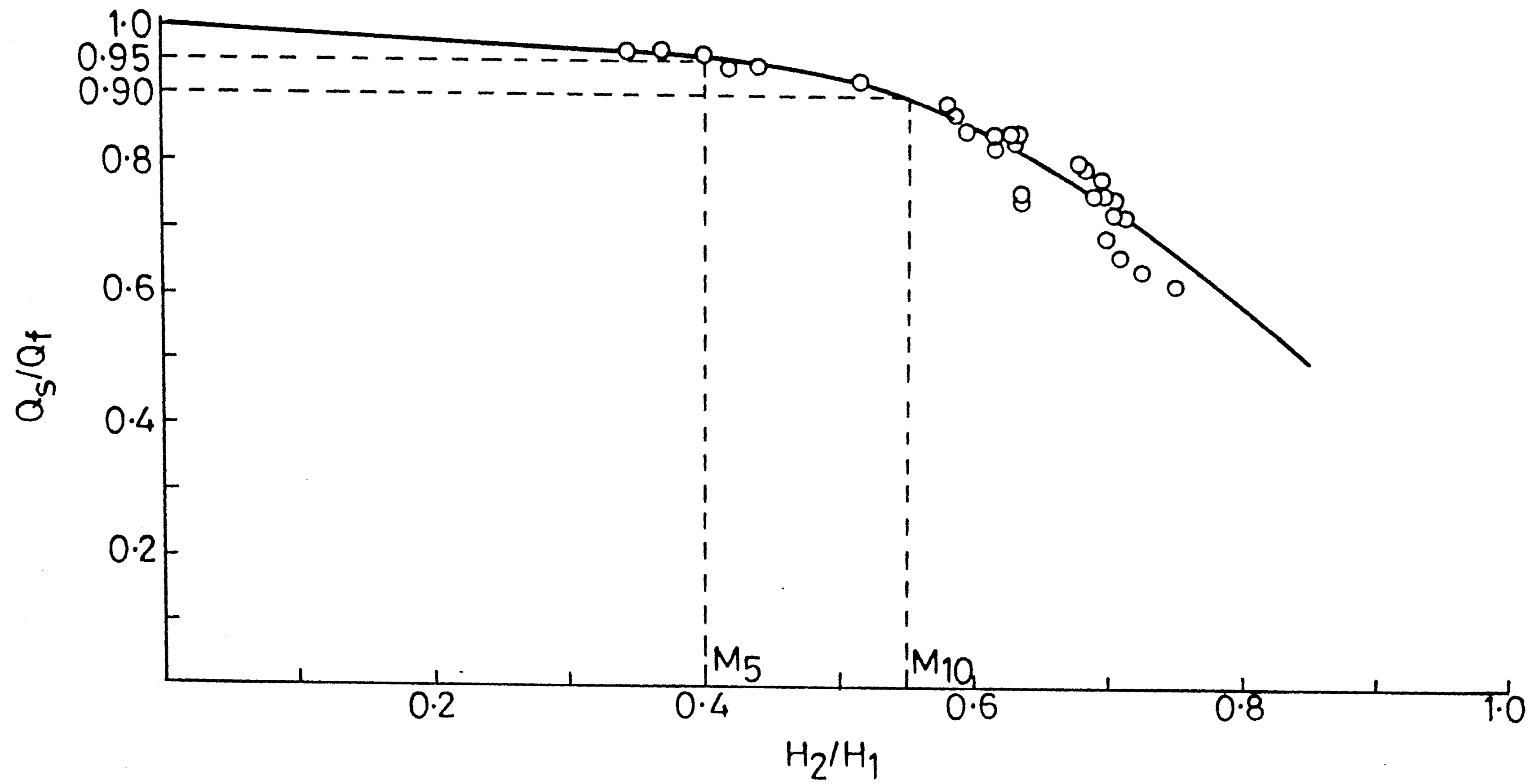

Fig. B. 3.1.1 Variation of Q_s/Q_f with H_2/H_1 for quadratic weir (n=0·5)

FIG. 3·1

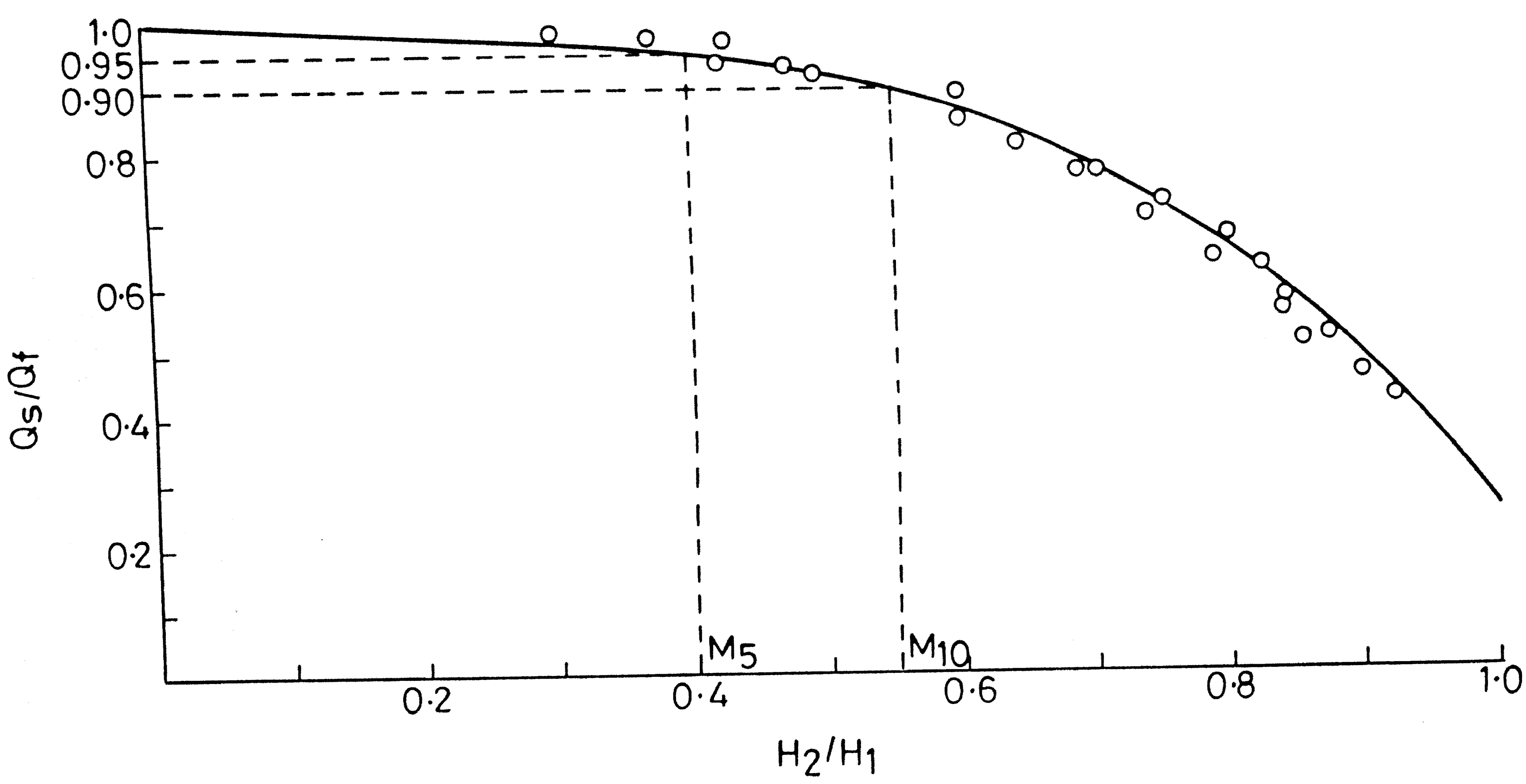

Fig. B.3.1.2 Variation of Q_s/Q_f with H_2/H_1 for linear proportional weir (n=1·0)

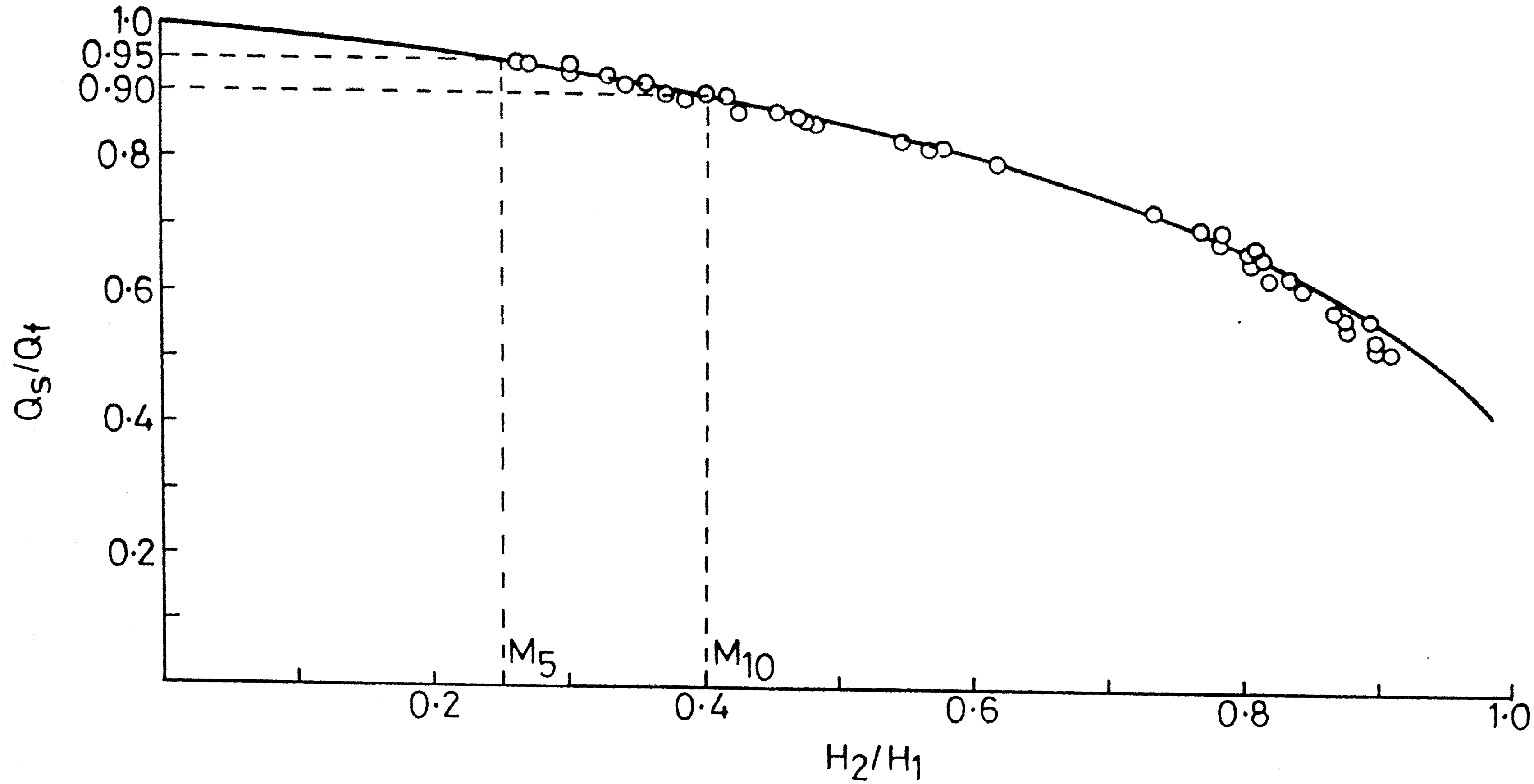

Fig. B. 3.1.3 Variation of Q_s/Q_f with H_2/H_1 for rectangular weir ($n = 1{\cdot}5$)

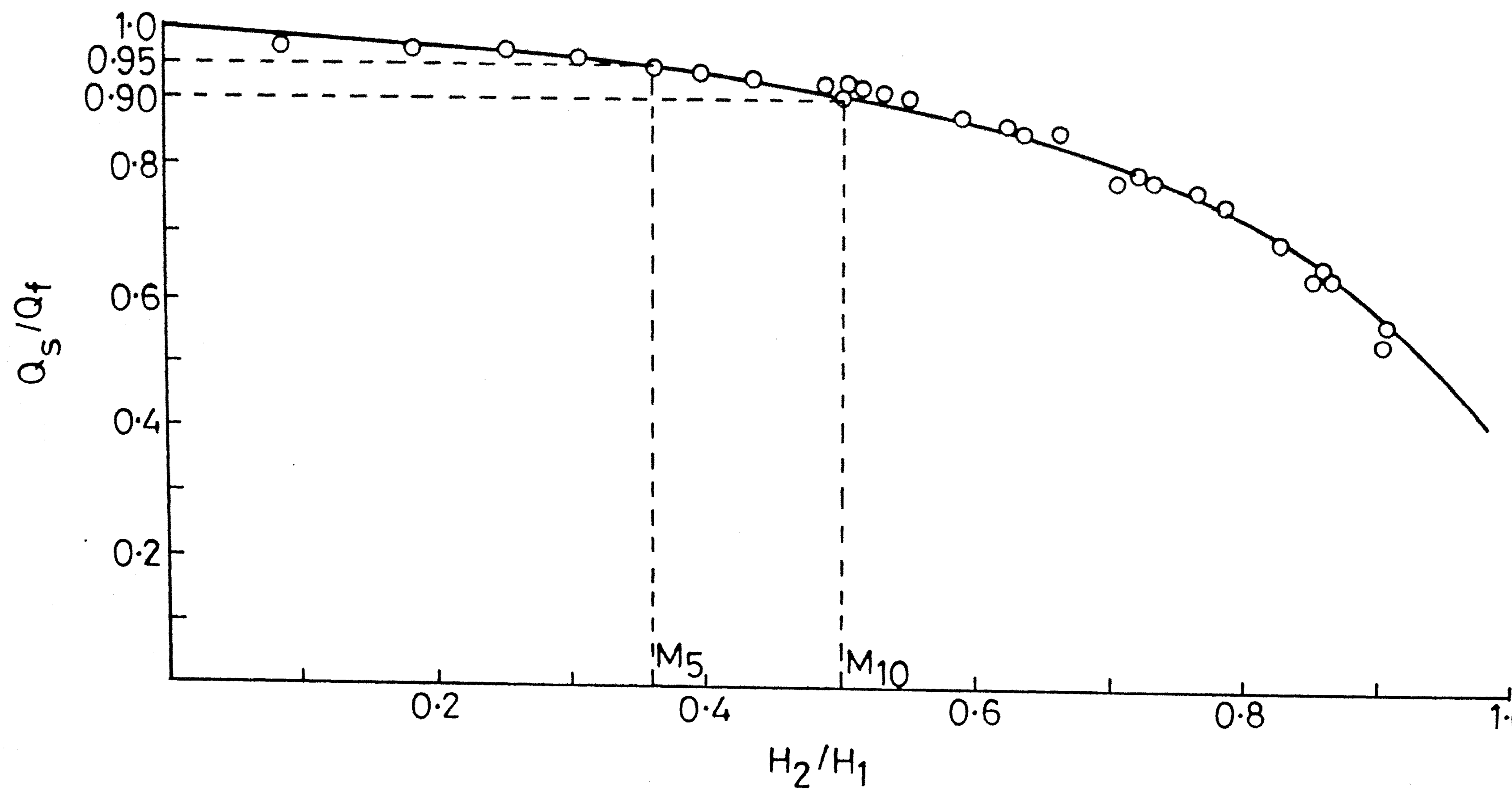

Fig. B.3.1.4 Variation of Q_s/Q_t with H_2/H_1 for parabolic weir ($n=2{\cdot}0$)

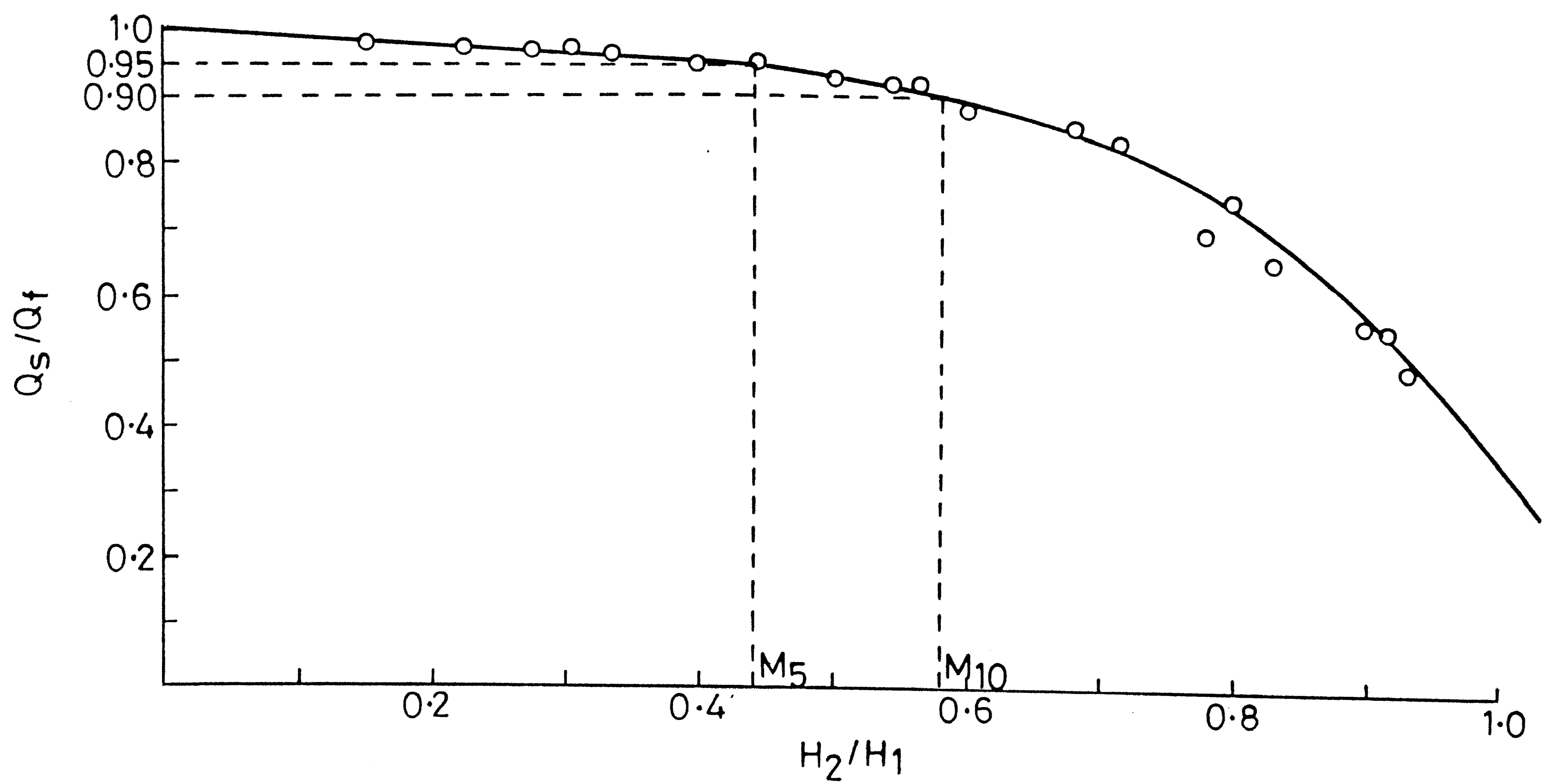

Fig. B.3.1.5 Variation of Q_s/Q_f with H_2/H_1 for 90°-Triangular weir ($n = 2{\cdot}5$)

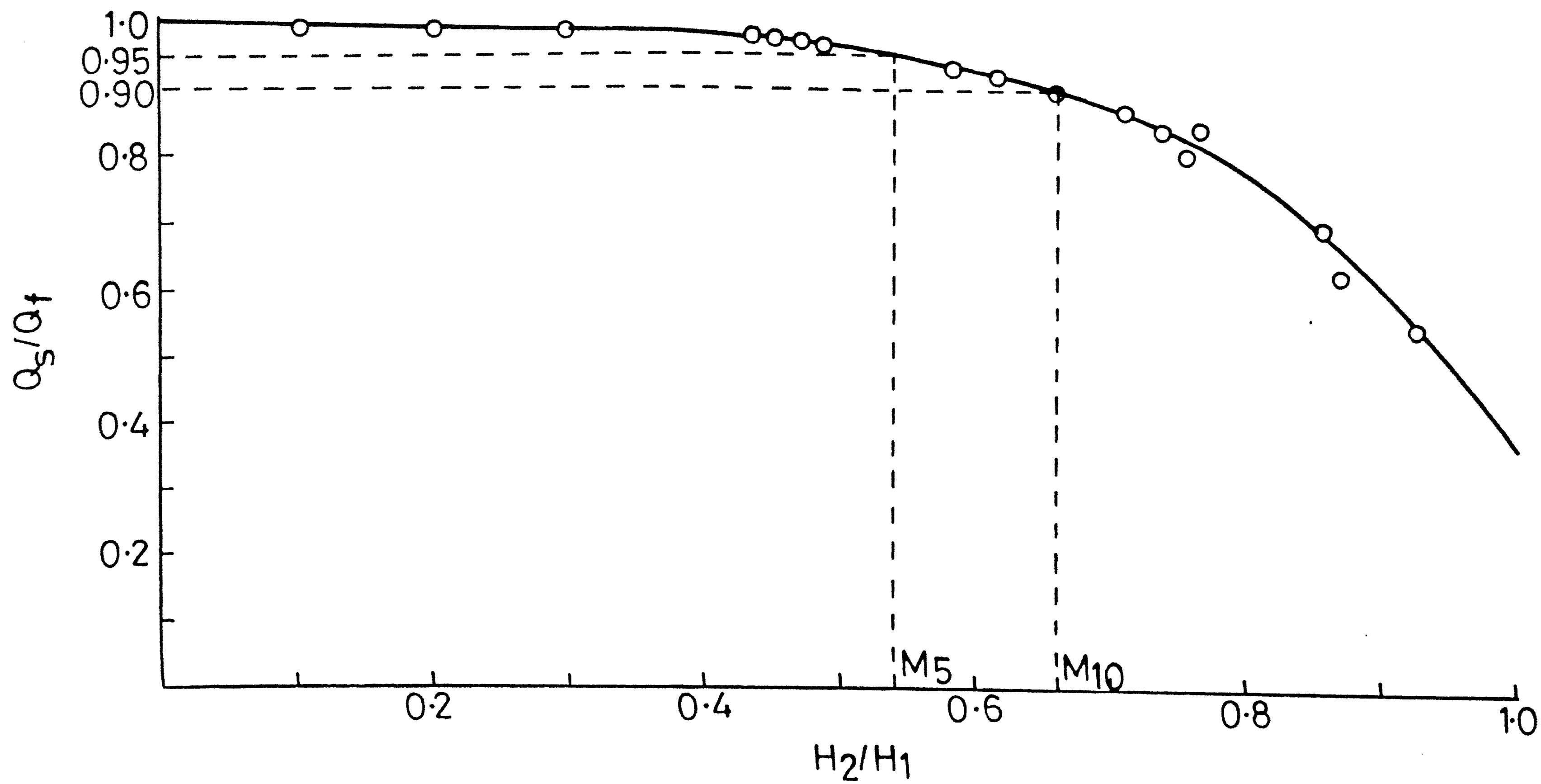

Fig.B.3.1.6 Variation of Q_s/Q_f with H_2/H_1 for cusp parabolic weir ($n=2{\cdot}0$)

$$Q_r = K_s \; H_r^m \qquad (B.3.4)$$

B.3.2 Range of Variables in the Present Study

The range of variable used in the persent study for the submerged flow are as shown in Table B.3.2.

It may be mentioned that compared to Villemonte work (Table (B.2.2)), the following points also have been incorporated in the present work.

(i) The variable $\frac{P}{H}$ cover the lower range 1.0 not studied by Villemonte.

(ii) The quadratic weir (n = 0.5) not studied by Villemonte extends the range of weirs with $n < 1.5$.

B.3.3 Calculation of the Value of K_s and m

Using the equation $Q_r = K_s \; H_r^m$ the value of m for $K_s = 1.0$ were calculated for each weir shape in the present weir study; for the whole range of submergences, by regression analysis. The value obtained for different weirs are shown in Table (B.3.3).

It is seen that the value of m are different from the Villemonte of 0.385. For an observed head set of H_1 and H_2 the submerged flow discharge was calculated from the equation

$$\frac{Q_s}{Q_f} = K_s \left[1 - \left(\frac{H_2}{H_1}\right)^n \right]^m \qquad (B.1.5)$$

Using the appropriate K_s and m as in Table B.3.4 and the error prediction was found by comparing the estimated discharge Q_s with the observed discharge.

Table (B.3.2)

Variables of Present Study

P = 0.15 metre constant for all weirs

Sl. No.	Type of weir	Exponents n Notional	Exponents n Experimental	Range of discharge in m^3/sec	$H_r = 1-(\frac{H_2}{H_1})^n$	$Q_r = \frac{Q_s}{Q_f}$	P/H	Number of observation
1.	Quadratic weir	0.5	0.46	0.0415-0.06	0.12-0.40	0.60-0.96	0.4-0.60	36
2.	Linear proportional weir	1.0	0.96	0.03-0.08	0.09-0.70	0.45-0.99	0.30-1.00	41
3.	Rectangular weir	1.5	1.5077	0.045-0.06	0.14-0.93	0.50-0.98	0.70-1.10	45
4.	Parabolic weir	2.0	2.087	0.03-0.05	0.20-0.97	0.55-0.99	0.45-0.70	36
5.	Triangular 90^o weir	2.5	2.637	0.15-0.025	0.18-0.99	0.50-0.99	0.63-0.80	30
6.	Cusp parabolic weir	3.5	3.428	0.012-0.016	0.40-0.99	0.55-0.99	0.60-0.80	25

Table (B.3.3)

For Whole Range of Submergences Value of m for (K_s = 1.0)

Data for Present Study

Sl.No.	Type of weirs	n	m	Coefficient of correlation
1.	Quadratic weir	0.468	0.147	0.930
2.	Linear proportional weir	0.963	0.263	0.988
3.	Rectangular weir	1.5077	0.373	0.997
4.	Parabolic weir	2.087	0.340	0.994
5.	Triangular 90° weir	2.637	0.365	0.992
6.	Cusp parabolic weir	3.420	0.399	0.966

It is seen that the Rms percentage error against observed discharge for quadratic and linear proportional weirs are 9.106 and 9.103 respectively. However for other weirs $n \geq 1.5$ the Rms percentage errors are in the range 1.976 to 3.814.

Next the Villemonte data along with the data of present study were analysed as one group, with $K_s = 1.0$ in the equation (B.3.4) and the value of m were calculated by regression analysis for each weir. (Table B.3.4) shows the result.

Table B.3.4

The value of m for all Range of Submergence for $K_s = 1$
For the Data (Present Study + Villemonte)

Sl.No.	Type of weirs	n	m	Coefficient of correlation
1.	Quadratic weir	0.5	0.1534	0.925
2.	Linear proportional weir	1.0	0.2955	0.940
3.	Rectangular weir	1.5	0.3719	0.991
4.	Parabolic weir	2.0	0.3660	0.983
5.	Triangular 90^{o}-weir	2.5	0.3940	0.994
6.	Cusp parabolic weir	3.4	0.4029	0.989

By comparing the Table B.3.4 with the Table B.3.3 it is seen that the value of exponent m slightly increased. The observed discharge was compared with submerged flow discharge calculated from equation (B.1.5) using appropriate value of K_s and m from the Table B.3.4 and the error prediction was found out.

The Rms percentage error obtained against observed discharge for quadratic and sutro weirs are 8.82 and 9.68 percent respectively. In the case of $n \geq 1.5$ the Rms percentage errors found within 3.75. Due to the higher value of errors against observed discharge for quadratic and linear proportional weir, it was thought that the submerged flow discharge should be divided into two zones of submergence ratio and the value of m and K_s should be obtained for better result.

By trial and error different range of submergence ratios were selected to split up the data into two ranges of submergence. The value of K_s and m were obtained by regression analysis in that range. For particular range of submergence error were calculated.

The optimal two ranges of submergence were selected as: first zone 05 to 50 percent of submergence and second zone 40 to 95 percent submergence zone. The combined data of the present study and Villemonte data were considered in these two ranges. For submergence in second zone (40-95) percent the value of K_s and m were calculated by regression analysis shown in Table B.3.5.

Table B.3.5

For Date (Present Study + Villemonte)

The Value of K_s and m for Submergence (42-95) Percent

Sl.No.	Type of weirs	n	k_s	m	Coefficient of correlation
1.	Quadratic weir	0.5	1.61	0.42	0.918
2.	Linear proportional weir	1.0	1.14	0.38	0.900
3.	Rectangular weir	1.5	0.97	0.34	0.988
4.	Parabolic weir	2.0	1.072	0.417	0.980
5.	Triangular 90^o weir	2.5	1.023	0.4112	0.993
6.	Cusp parabolic weir	3.4	1.012	0.4118	0.993

Since K_s = f(n) and m = f(n) had no good convenient correlation, a small change was made in K_s and m values to obtain convenient correlation with n for easy practical use. Thus the selected value of K_s and m are:

$$K_s = 1.46 - 0.46\ (n - 0.5) \qquad \text{(B.3.5)}$$

$$\text{for } 0.5 < n < 1.5$$

$$K_s = 1.0 \qquad n \geq 1.5$$

$$m = 0.37$$

$$\text{For } 0.5 \leq n \leq 3.5$$

In the Fig. B.3.2 the graphical representation of variation of value of K_s and m with n are shown. It is noted that this result is not the optimal correlation equation but the results are convenient and adequate for practical use. The error in the prediction of discharge was found by the equation

$$\frac{Q_s}{Q_f} = K_s\ [1 - (\frac{H_2}{H_1})^n\ ]^m \qquad \text{(B.1.5)}$$

against observed value is shown in Table B.3.6. The value of K_s and m were selected from equation (B.3.5). The minimum Rms percentage error was obtained for cusp parabolic weir (i.e. 2 percent) and the maximum Rms percentage error was for the quadratic weir (i.e. 5 percent). In Table B.3.8 the Rms percentage error for each weir is shown.

TABLE B.3.6

ERROR IN DISCHARGE ESTIMATION IN ZONE II SUBMERGENCE RATIO(40-95)PERCENT

BY EQUATION $Qs/Qf=Ks(1-(H2/H1)^{n})^{m}$

$Ks=1.46-.46(n-0.5)$ for $0.5< n >1.5$

$Ks=1.0$ for $n>1.5$

$m=0.37$

TABLE B.3.6.1

QUADRATIC WEIR m=.37 Ks=1.46

(Qs)	(Qw)	(Qe)	(Hr)	(Pe)
50.617	33.635	47.699	.73781	-6.1178
49.498	32.906	47.699	.73032	-3.7710
48.329	32.124	47.699	.73331	-1.3215
47.948	31.906	47.699	.71455	-.5223
46.916	31.214	47.699	.71698	1.6426
47.050	31.317	47.699	.70992	1.3603
45.707	30.424	47.699	.70885	4.1763
44.435	29.611	47.699	.68821	6.8431
44.809	29.943	47.699	.63246	6.0587
44.295	29.595	47.699	.63645	7.1356
46.025	30.906	47.699	.51497	3.5107
60.245	40.247	57.865	.63837	-4.1120
56.161	37.552	57.865	.61920	2.9451
55.568	37.169	57.865	.61101	3.9707
56.174	37.600	57.865	.59541	2.9223
55.762	37.348	57.865	.58057	3.6347
56.963	38.229	57.865	.52980	1.5597
55.435	36.905	50.995	.70654	-8.7069
53.780	35.823	50.995	.69598	-5.4606
53.108	35.373	50.995	.69797	-4.1447
51.559	34.337	50.995	.69987	-1.1062
49.700	33.117	50.995	.69003	2.5388
49.912	33.264	50.995	.68663	2.1235
47.919	31.947	50.995	.67984	6.0321
47.315	31.546	50.995	.67879	7.2162
48.541	32.441	50.995	.62979	4.8119
47.825	31.974	50.995	.62197	6.2163
48.815	32.706	50.995	.57222	4.2747
49.183	32.984	50.995	.54924	3.5521

DISCHARGE IN Litres/sec

=estimated submerged flow discharge for Ks=1.46 m=0.37

=estimated submerged flow discharge by Villemonte equation (Villemonte value of Ks and m)

=experimental submerged flow discharge

=submergence ratio

=percentage error in submerged flow discharge estimation between Qs and Qe

TABLE B.3.6.2

SUTRO WEIR M=.37 Ks=1.23

(Qs)	(Qw)	(Qe)	(Hr)	(Pe)
59.236	46.484	54.185	.90209	-9.3216
55.843	44.466	54.185	.74181	-3.0605
54.896	43.924	54.185	.64402	-1.3119
54.754	43.886	54.185	.60153	-1.0504
54.468	43.803	54.185	.50370	-.5235
54.452	43.454	54.185	.70142	-.4940
57.320	45.493	54.185	.79217	-5.7857
56.135	44.362	54.185	.84366	-3.5997
57.980	45.668	54.185	.87460	-7.0034
82.439	65.227	82.620	.83074	.2191
81.507	64.676	82.620	.79500	1.3472
81.670	64.983	82.620	.75426	1.1493
80.924	64.853	82.620	.60491	2.0527
37.397	29.568	34.256	.83851	-9.1689
35.945	28.474	34.256	.81687	-4.9316
35.567	28.257	34.256	.77801	-3.8284
35.072	28.005	34.256	.68925	-2.3841
34.315	27.464	34.256	.63811	-.1734
35.179	28.291	34.256	.50383	-2.6965
47.230	37.491	44.702	.78988	-5.6562
47.210	37.356	44.702	.82973	-5.6098
44.809	35.846	44.702	.64929	-.2406
45.809	36.582	44.702	.68686	-2.4758
46.180	36.804	44.702	.72616	-3.3061
46.930	37.368	44.702	.74199	-4.9844
45.419	36.442	44.702	.57292	-1.6042

DISCHARGE IN Litres/sec

Qs=estimated submerged flow discharge for Ks=1.23 m=0.37

Qw=estimated submerged flow discharge by Villemonte equation (Villemonte value of Ks and m)

Qe=experimental submerged flow discharge

Hr=submergence ratio

Pe=percentage error in submerged flow discharge estimation between Qs and Qe

TABLE B.3.6.3

RECTANGULAR WEIR M=.37 Ks=1.00

(Qs)	(Qw)	(Qe)	(Hr)	(Pe)
55.356	53.843	57.439	.89245	3.62734
55.876	54.501	57.439	.86952	2.72177
57.461	56.318	57.439	.81740	-.03711
57.443	56.335	57.439	.80940	-.00575
57.308	56.235	57.439	.80165	.22828
57.632	56.708	57.439	.75888	-.33520
59.868	59.288	57.439	.61224	-4.22819
60.937	60.443	57.439	.56180	-6.08968
44.484	43.225	45.093	.89953	1.35014
45.827	44.688	45.093	.87182	-1.62731
44.450	43.393	45.093	.86180	1.42559
44.846	43.887	45.093	.83605	.54761
44.700	43.785	45.093	.82485	.87124
45.324	44.437	45.093	.81310	-.51163
45.032	44.175	45.093	.80579	.13568
45.362	44.597	45.093	.77287	-.59601
44.961	44.193	45.093	.77681	.29169
45.235	44.599	45.093	.72110	-.31549
47.402	47.002	45.093	.57262	-5.12030
50.975	49.567	51.933	.89466	1.84472
49.355	48.072	51.933	.88182	4.96333
50.589	49.603	51.933	.81219	2.58839
50.206	49.261	51.933	.80293	3.32526
53.090	52.507	51.933	.64895	-2.22803
54.514	54.104	51.933	.54019	-4.96936
54.152	53.799	51.933	.50164	-4.27247

DISCHARGE IN Litres/sec

Qs=estimated submerged flow discharge for Ks=1.00 m=0.37

Qw=estimated submerged flow discharge by Villemonte equation (Villemonte value of Ks and m)

Qe=experimental submerged flow discharge

Hr=submergence ratio

Pe=percentage error in submerged flow discharge estimation between Qs and Qe

TABLE B.3.6.4
PARABOLIC WEIR M=.37 Ks=1.00

(Qs)	(Qw)	(Qe)	(Hr)	(Pe)
33.003	32.839	33.797	.54584	2.34833
32.380	32.121	33.797	.65587	4.19075
32.612	31.981	33.797	.85921	3.50420
34.312	33.502	33.797	.89692	-1.52570
32.624	32.009	33.797	.85361	3.47016
34.457	34.118	33.797	.70556	-1.95525
32.887	32.649	33.797	.63202	2.69026
33.067	32.871	33.797	.58551	2.16044
46.674	46.041	48.674	.78122	4.10982
47.194	46.431	48.674	.82118	3.04022
47.461	46.561	48.674	.85480	2.49204
47.207	46.079	48.674	.89894	3.01458
46.111	45.356	48.674	.82409	5.26475
46.432	45.848	48.674	.76389	4.60526
46.486	46.112	48.674	.65701	4.49511
47.123	46.903	48.674	.53158	3.18736
47.286	47.085	48.674	.51159	2.85254
39.895	39.658	40.357	.58622	1.14425
39.464	39.185	40.357	.62619	2.21257
39.449	39.131	40.357	.65774	2.25074
39.111	38.690	40.357	.72661	3.08838
38.146	37.539	40.357	.81780	5.47820
39.207	38.799	40.357	.71881	2.84985
39.382	39.149	40.357	.58504	2.41598

DISCHARGE IN Litres/sec

Qs=estimated submerged flow discharge for Ks=1.00 m=0.37
Qw=estimated submerged flow discharge by Villemonte equation
(Villemonte value of Ks and m)
Qe=experimental submerged flow discharge
Hr=submergence ratio
Pe=percentage error in submerged flow discharge estimation
between Qs and Qe

TABLE B.3.6.5
TRIANGULAR 90-DEGREE WEIR

(Qs)	(Qw)	(Qe)	(Hr)	(Pe)
19.920	19.866	20.050	.50349	.64898
19.966	19.873	20.050	.60748	.41770
19.771	19.646	20.050	.66719	1.39212
19.659	19.502	20.050	.71649	1.94724
19.432	19.200	20.050	.79712	3.08251
19.799	19.344	20.050	.91333	1.25239
19.228	19.025	20.050	.77238	4.10052
19.636	19.562	20.050	.56578	2.06228
19.737	19.672	20.050	.54287	1.55782
22.838	22.706	23.023	.64965	.80505
22.776	22.613	23.023	.69295	1.07410
22.607	22.375	23.023	.76729	1.80778
22.581	22.216	23.023	.85566	1.92019
22.680	22.207	23.023	.89879	1.48872
22.040	21.777	23.023	.79763	4.26877
22.097	21.840	23.023	.79250	4.02170

TABLE B.3.6.6
CUSP PARABOLIC WEIR M=.37 Ks=1.00

(Qs)	(Qw)	(Qe)	(Hr)	(Pe)
15.342	15.300	15.348	.59365	.03729
15.125	14.953	15.348	.83274	1.45217
15.243	15.203	15.348	.58583	.68269
15.204	15.155	15.348	.61706	.94022
15.378	15.277	15.348	.73859	-.19449
15.951	15.840	15.348	.75091	-3.93270
14.995	14.883	15.348	.76199	2.29808
15.067	14.983	15.348	.71088	1.83345
12.520	12.377	12.517	.83270	-.02055
12.626	12.459	12.517	.85674	-.86881
12.723	12.443	12.517	.92776	-1.64143
12.480	12.441	12.517	.61376	.29866
12.492	12.455	12.517	.60432	.20391
13.306	13.203	12.517	.76835	-6.30028
12.482	12.448	12.517	.59043	.28518

DISCHARGE IN Litres/sec

Qs=estimated submerged flow discharge for Ks=1.00 m=0.37
Qw=estimated submerged flow discharge by Villemonte equation
(Villemonte value of Ks and m)
Qe=experimental submerged flow discharge
Hr=submergence ratio
Pe=percentage error in submerged flow discharge estimation
between Qs and Qe

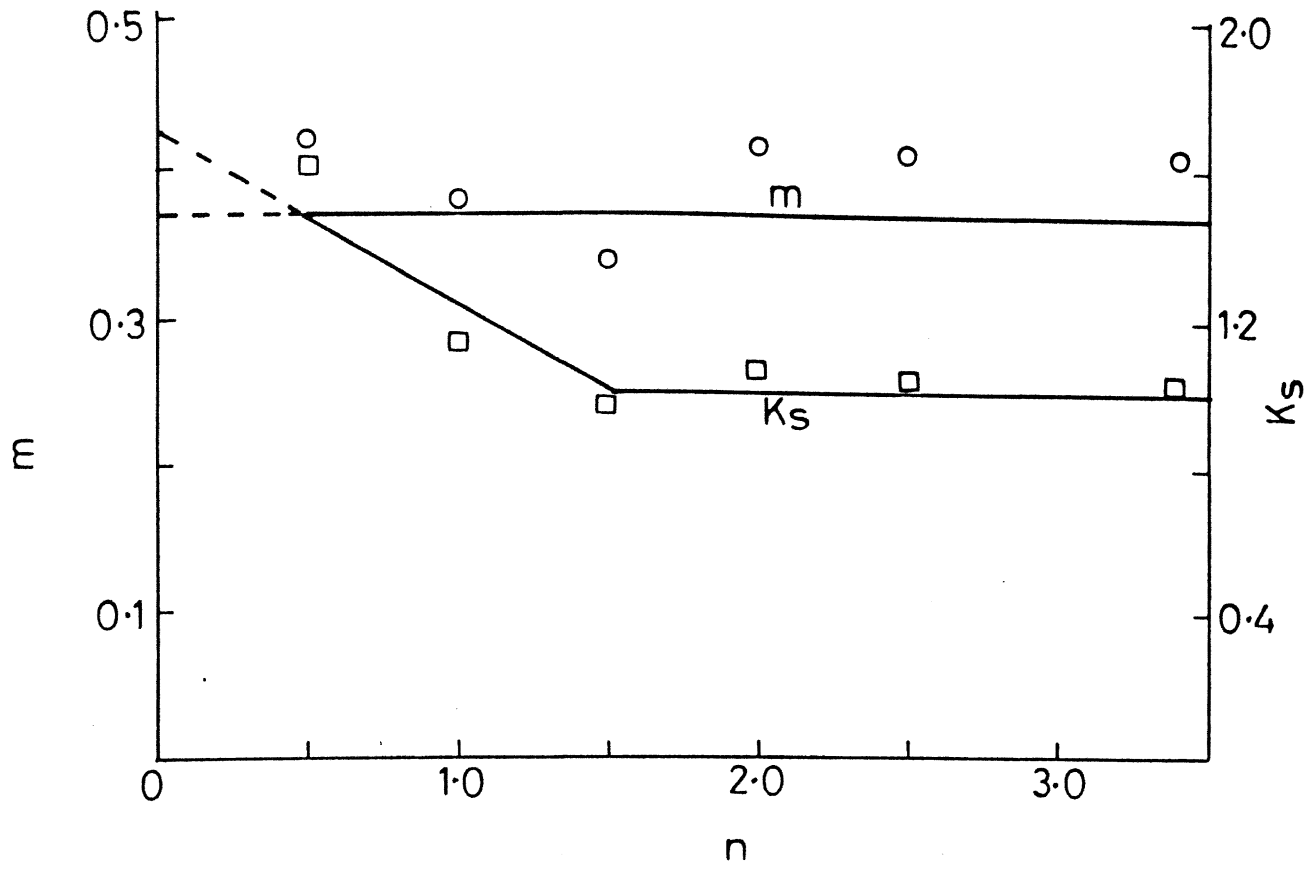

Fig.B.3.2 Variation of K_s and m with n for submergence ratio 40 to 95 percent

For zone I with submergence five to fifty percent the value of K_s and m were calculated for the best correlation in the equation (B.3.4) by regression analysis and values of K_s and m obtained are shown in the Table B.3.7.

Table B.3.7

For Data (Present Study + Villemonte)

The value of K_s and m for submergence (5 - 50) percent

Sl.No.	Type of weirs	n	K_s	m	Coefficient of correlation
1.	Quadratic weir	0.5	1.073	0.108	0.850
2.	Linear proportional weir	1.0	1.096	0.211	0.800
3.	Rectangular weir	1.5	0.9907	0.354	0.970
4.	Parabolic weir	2.0	0.9844	0.286	0.970
5.	Triangular 90^{o} weir	2.5	0.9889	0.294	0.980
6.	Cusp parabolic weir	3.4	1.004	0.365	0.988

Since in the range of submergence ratio five to fifty percent the value of $K_s = f(n)$, and $m = f(n)$ had no good correlation. So optimal value of K_s and m as shown in Table B.3.7 were not used and for practical use the value of K_s and m were taken as

$$K_s = 1.08 \quad \text{for } n \leq 1.0$$

$$K_s = 1.00 \quad \text{for } n \geq 1.5$$

$$m = 0.13 + 0.24\ (n - 0.5) \text{ for } n \leq 1.5$$

$$m = 0.37 \text{ for } n \geq 1.5 \qquad \text{(B.3.6)}$$

The graphical representation of the variation of the values of K_s and n are shown in Fig. (B.3.3). The Table B.3. 9 show the relationship between submergence ratio and percentage error in the submerged flow discharge estimation against observed discharge.

The flow discharge estimation was done using equation

$$\frac{Q_s}{Q_f} = K_s\ [1 - (H_2/H_1)^n]^m \qquad \text{(B.1.5)}$$

by using appropriate optimal value of K_s and m from Eq. (B.3.7).

It is seen that the maximum Rms error is three percent for linear proportional weir and minimum Rms error is for the cusp parabolic weir with a value of 0.4 percent. In the Table (B.3.8) the Rms percentage error for each weir in the submergence ratio zone I of five to fifty percent are shown along with zone II for fifty to ninety five percent submergence ratio.

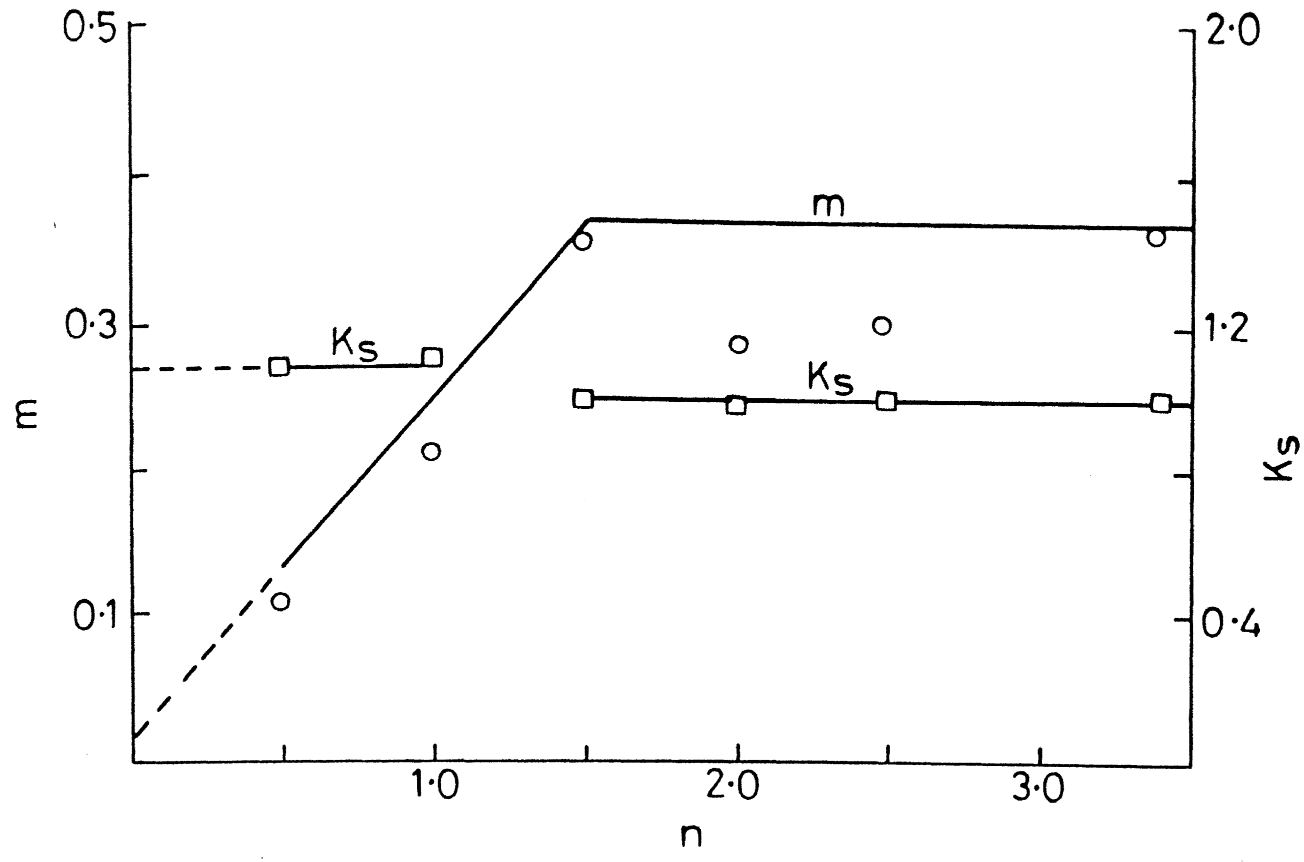

Fig. B.3.3 Variation of K_S and m with n for submergence ratio 5 to 50 percent

TABLE B.3.9

ERROR IN DISCHARGE ESTIMATION IN ZONE I SUBMERGENCE RATIO(5-50)PERCEN

BY EQUATION $Qs/Qf=Ks(1-(H2/H1)^n)^m$

Ks=1.08 for 0.5< n >1.0

Ks=1.0 for n>1.5

m=0.13+.24(n-.5) for n<1.5

m=0.37 for n>1.5

TABLE B.3.9.1

QUADRATIC WEIR m=.13 Ks=1.08

(Qs)	(Qw)	(Qe)	(Hr)	(Pe)
46.732	30.906	47.699	.51497	2.02656
46.449	32.752	47.699	.40711	2.62182
57.545	40.287	57.865	.41982	.55359
57.632	42.023	57.865	.34587	.40380
49.922	34.528	50.995	.44103	2.10450
49.818	35.940	50.995	.36566	2.30819

TABLE B.3.9.2

LINEAR PROPORTIONAL WEIR m=.25 Ks=1.08

(Qs)	(Qw)	(Qe)	(Hr)	(Pe)
52.300	44.236	54.185	.47499	3.47772
52.115	44.311	54.185	.45455	3.82081
52.700	45.619	54.185	.37863	2.73985
53.642	47.913	54.185	.22111	1.00097
52.188	43.803	54.185	.50370	3.68481
78.314	68.089	82.620	.35857	5.21202
78.763	67.470	82.620	.42416	4.66817
33.708	28.291	34.256	.50383	1.59953
34.100	30.014	34.256	.29895	.45580
33.982	29.288	34.256	.39797	.80059
43.674	36.790	44.702	.49036	2.29972
43.290	37.850	44.702	.33195	3.15894

DISCHARGE IN Litres/sec

Qs=estimated submerged flow discharge

Ks=1.08 m=0.13 for quadratic weir

Ks=1.08 m=0.25 for linear proportional weir

Qw=estimated submerged flow discharge by Villemonte equation (Villemonte value of Ks and m)

Qe=experimental submerged flow discharge

Hr=submergence ratio

Pe=percentage error in submerged flow discharge estimation between Qs and Qe

TABLE B.3.9.3

RECTANGULAR WEIR M=.37 Ks=1.00

(Qs)	(Qw)	(Qe)	(Hr)	(Pe)
58.748	58.413	57.439	.46658	-2.27876
58.701	58.387	57.439	.45051	-2.19650
58.840	58.630	57.439	.35747	-2.43863
58.571	58.407	57.439	.30881	-1.96966
58.855	58.724	57.439	.26933	-2.46508
58.789	58.559	57.439	.37768	-2.35049
59.323	59.070	57.439	.39641	-3.27867
45.948	45.713	45.093	.44045	-1.89703
45.748	45.574	45.093	.37020	-1.45173
45.877	45.743	45.093	.31726	-1.73937
46.033	45.958	45.093	.22187	-2.08439
51.588	51.277	51.933	.48120	.66466
52.227	51.970	51.933	.42956	-.56555
52.636	52.423	51.933	.38467	-1.35287
52.878	52.700	51.933	.34434	-1.81878
52.243	52.101	51.933	.30351	-.59721
52.535	52.419	51.933	.26887	-1.16007
52.714	52.620	51.933	.23410	-1.50362
52.496	52.404	51.933	.23333	-1.08503
52.820	52.782	51.933	.13142	-1.70879

TABLE B.3.9.4

PARABOLIC WEIR M=.37 Ks=1.00

(Qs)	(Qw)	(Qe)	(Hr)	(Pe)
33.691	33.465	33.797	.41852	.31276
34.211	34.105	33.797	.28790	-1.22672
34.603	34.567	33.797	.16268	-2.38580
34.738	34.731	33.797	.05888	-2.78473
47.554	47.085	48.674	.50074	2.30013
47.990	47.574	48.674	.47294	1.40548
48.767	48.507	48.674	.37869	-.19120
48.686	48.510	48.674	.31321	-.02379
49.126	49.024	48.674	.23846	-.92884
40.172	39.885	40.357	.43195	.45949
40.618	40.437	40.357	.34620	-.64703
41.179	41.100	40.357	.22718	-2.03631

DISCHARGE IN Litres/sec

Qs=estimated submerged flow discharge for Ks=1.00 m=.37

Qw=estimated submerged flow discharge by Villemonte equation (Villemonte value of Ks and m)

Qe=experimental submerged flow discharge

Hr=submergence ratio

Pe=percentage error in submerged flow discharge estimation between Qs and Qe

TABLE B.3.9.5
TRIANGULAR 90-DEGREE WEIR

(Qs)	(Qw)	(Qe)	(Hr)	(Pe)
20.212	20.171	20.050	.33551	-.80966
20.098	20.012	20.050	.44138	-.24031
19.991	19.866	20.050	.50349	.29307
20.007	19.943	20.050	.39620	.21461
20.122	20.090	20.050	.30824	-.35977
20.250	20.245	20.050	.15372	-.99946
23.093	23.022	23.023	.39083	-.30377
23.157	23.118	23.023	.31489	-.58259
23.204	23.189	23.023	.22355	-.78741
23.264	23.242	23.023	.25518	-1.04847
23.284	23.251	23.023	.29494	-1.13543
23.240	23.190	23.023	.34381	-.94415
23.072	22.983	23.023	.42373	-.21136
22.944	22.821	23.023	.47646	.34444

TABLE B.3.9.6
CUSP PARABOLIC WEIR

(Qs)	(Qw)	(Qe)	(Hr)	(Pe)
15.295	15.295	15.348	.11229	.34142
15.271	15.261	15.348	.31513	.49844
15.298	15.293	15.348	.25725	.32517
15.274	15.241	15.348	.43838	.48011
15.264	15.220	15.348	.47646	.54735
12.479	12.467	12.517	.34426	.30929
12.527	12.488	12.517	.48907	-.07885

DISCHARGE IN Litres/sec

Qs=estimated submerged flow discharge for Ks=1.00 m=.37

Qw=estimated submerged flow discharge by Villemonte equation (Villemonte value of Ks and m)

Qe=experimental submerged flow discharge

Hr=submergence ratio

Pe=percentage error in submerged flow discharge estimation between Qs and Qe

Table B.3.8

Rms Percentage Error in Discharge Estimation

Sl.No.	Type of Weirs	n	Rms of percentage error Range of submergence ratio Zone I (5-50) percent	 Zone II (40-90) percent
1.	Quadratic weir	0.5	1.9	5.0
2.	Linear proportional weir	1.0	4.1	3.1
3.	Rectangular weir	1.5	1.8	2.8
4.	Parabolic weir	2.0	1.5	3.2
5.	Triangular 90° weir	2.5	0.7	2.3
6.	Cusp parabolic weir	3.4	0.4	2.2

From Table B.3.8 it is seen that all the weirs could be used in submerged condition with percentage error less than five percent. The different type of weirs tested can be arranged in the following order in accordance with their accuracy in discharge measurement in submerged mode:

(1) Cusp parabolic weir

(2) Triangular weir

(3) Parabolic weir

(4) Rectangular weir

(5) Linear proportional weir

(6) Quadratic weir.

It is interesting to note that the cusp parabolic and triangular weir can be used for discharge measurement in submerged condition upto seventy percent submergence ratio with an error within one percent.

B.3.4 The Study of Modularity Limit:

The variation of the observed values Q_r with H_2/H_1 for various weir shapes is shown in Fig. (B.3.1). It is usual to define a modular limit of flow measuring device as the maximum ratio of tailwater head to the upstream head (both measured above the common datum, usually the crest) at which flow is not affected. To give a qualitative value of the head ratio H_2/H_1 at which significant changes in the discharge Q_f would take place. The modular limit M_5 and M_{10} are defined as below:

M_5 = Modular limit at five percent level: It is defined as the value of submergence ratio H_2/H_1 at which the real discharge in submerged mode deviates by five percent from the discharge calculated by the head discharge equation of free flow.

M_{10} = Modular limit at ten percent: It is defined as the value of submergence ratio H_2/H_1 at which the real discharge in submerged mode deviates by ten percent from the discharge calculated by free mode discharge equation.

The value of M_5 and M_{10} for the various weir shapes obtained by interpolation from the plot of Q_r vs. H_2/H_1 (i.e. Fig. (B.3.1)) are shown in Table B.3.10:

Table B.3.10

The Value of M_5 and M_{10} for Each Weir

Sl.No.	Type of weir	n	M_5	M_{10}
1.	Quadratic weir	0.5	0.40	0.55
2.	Linear proportional weir	1.0	0.40	0.55
3.	Rectangular weir	1.5	0.25	0.40
4.	Parabolic weir	2.0	0.36	0.50
5.	Triangular 90^{o} weir	2.5	0.44	0.56
6.	Cusp parabolic	3.4	0.54	0.66

It is seen that (Table B.3.10) for the quadratic and sutro weirs the value of M_5 and M_{10} are constant at 0.40 and 0.55 respectively. But for rectangular, parabolic, 90^{o}-triangular and cusp parabolic weirs (i.e. $n \geq 1.5$) the modular limit (M) varies as function of n.

$$\text{Considering } M = f(n) = a(n-1.5)^{b} + C \qquad (B.3.8)$$

By regression analysis the value of a and b was found out in equation (B.3.8) taking the initial value of M at n=1.5. So the value of M_5 and M_{10} can be expressed as

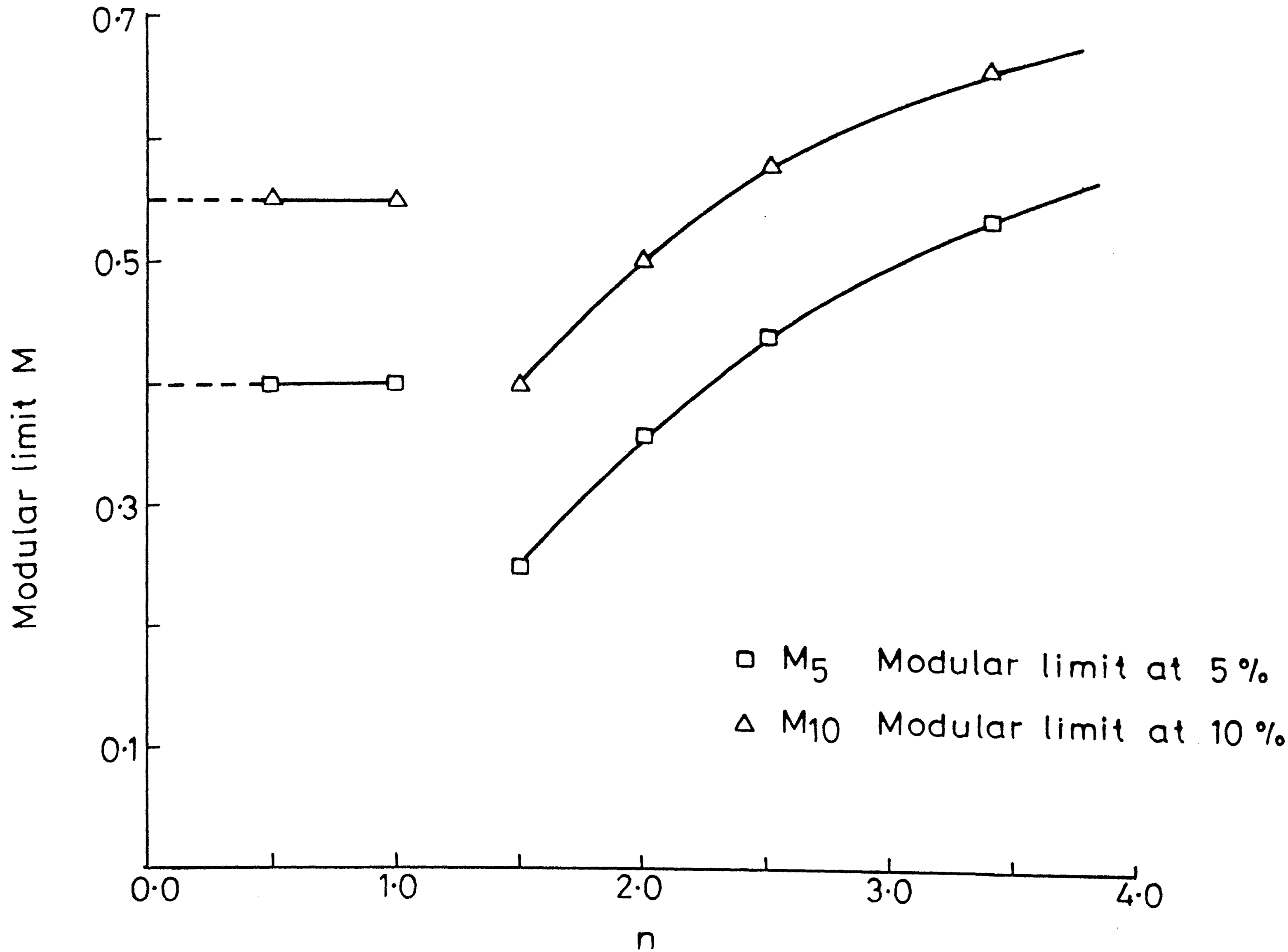

Fig. B.3.4 Variation of modular limit with n

$$M_5 = 0.185\ (n-1.5)^{.727} + 0.25 \qquad \text{(B.3.9)}$$
$$\text{For } n \leq 1.5$$

$$M_{10} = 0.163\ (n-1.5)^{.715} + 0.40 \qquad \text{(B.3.10)}$$
$$\text{For } n \leq 1.5$$

The value of M_5 and M_{10} can also be calculated by equation

$$\frac{Q_s}{Q_f} = K_s\ [1 - (H_2/H_1)^n]^m \qquad \text{(B.1.5)}$$

by selecting proper value of K_s and m. However the equations (B.3.9) and (B.3.10) is believed to be useful in quick estimation of the possible submergence effect.

CHAPTER 4

CONCLUSIONS AND RECOMMENDATIONS

4.1 Conclusions

Based on an experimental study of the submerged flow in six kinds of weir shape, the following significant conclusions are obtained.

In the generalised form of Villemonte equation

$$\frac{Q_s}{Q_f} = K_s \left[1 - \left(\frac{H_2}{H_1}\right)^n\right]^m \qquad (B.1.5)$$

the variation of the value of K_s and m were obtained for all the weir shapes.

(1) For all the weir shapes tested, in general the value of K_s and m, obtained from the regression analysis of the data, are different from $K_s = 1.0$ and $m = 0.385$ suggested by Villemonte.

(2)(a) If $K_s = 1.0$ is taken, then for weirs with $n \geq 1.5$ (viz., rectangular, triangular, parabolic and cusp parabolic) the corresponding value of m is very near 0.385. In other words, the Villemonte equation can be used in these weir shapes to predict the discharge within an error of about five percent.

(b) However, if $K_s = 1.0$ is taken for weirs with $n < 1.5$ (i.e. linear proportional and quadratic weirs) the experimental data correlation gives $m = 0.15$, for quadratic weirs and $m = 0.26$ for linear (sutro) weir against the Villemont's recommended value of 0.385. As such, the use

of Villemonte equation in these weirs may lead to large errors, upto as much as 25%.

(3) For convenience of discharge prediction two zones of submergence as below are suggested:

Zone I: Submergence 5 to 50 percent

Zone II: Submergence 40 to 95 percent.

For zone I, based on the experimental data, the following values of K_s and m are suggested in the generalised form of Villemonte equation (B.2.5)

For submergence (5-50) percent

$$K_s = 1.08 \qquad \text{for } 0.5 < n < 1.0$$

$$K_s = 1.00 \qquad \text{for } n \geq 1.5$$

$$\text{and} \quad m = 0.13 + 0.24(n-0.5) \qquad (B.3.7)$$

These values of K_s and m if used in the equation (B.2.5) prediction of discharge with an accuracy of 97 percent for all weirs can be expected.

For zone II, based on the experimental data, the following values of K_s and m are suggested for the equation (B.2.5)

For submergence 40 to 95 percent

$$K_s = 1.0 \qquad \text{for } n \geq 1.5$$

$$K_s = 1.46-0.46(n-0.5) \qquad \text{for } 0.5 \leq n \leq 1.5 \qquad (B.3.5)$$

$$\text{and } m = 0.37 \qquad \text{for } 0.5 \leq n \leq 3.5$$

If these values of K_s and m are used in equation (B.2.5) for submerged flow discharge estimation discharges with an accuracy of ninety five percent for all weirs can be expected.

(4) The modular limit at five percent level (M_s) and ten percent level (M_{10}) are studied and their values are obtained as follows:

$$M_5 = 0.40 \quad \text{for } 0.5 \leq n \leq 1.0$$

$$M_5 = 0.185\ (n-1.5)^{0.727}+0.25 \quad (\text{for } n \geq 1.5) \tag{B.3.9}$$

$$\text{and } M_{10} = 0.55 \text{ for } 0.5 \leq n \leq 1.0$$

$$M_{10} = 0.163\ (n - 1.5)^{0.715} + 0.40 \text{ for } n \geq 1.5 \tag{B.3.10}$$

(5) The triangular and cusp parabolic weirs are the best for discharge measurement in submerged flow conditions and in submergences upto 70 per-cent, the discharge can be measured by these weirs with an accuracy of 99 percent. The order of listing of weirs in term of their accuracy in discharge measurement in submerged mode are as follows:

Weirs	Percentage Rms error
(1) Cusp parabolic weir	1.8
(2) Triangular weir	2.0
(3) Parabolic weir	3.0
(4) Rectangular weir	3.0

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C                               PROGRAM SELECT
C       ----------------------------------------------------------------
C                               BY AMOD KUMAR
C       ----------------------------------------------------------------
C       A PROGRAM FOR SELECTION OF DISCHARGE MEASURING DEVICES.
C       THIS PROGRAM HELPS IN IDENTIFYING A SET OF POSSIBLE DISCHARGE
C       MEASSURING DEVICES FOR FLOW MEASUREMENT IN A GIVEN SITUATIONS
C       TWENTY SIX DEVICES ARE CONSIDERED.
C       ----------------------------------------------------------------
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     1  11x,'WITHOUT DISHARGE REGULATION'/)
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     1  10X,'FOR THE SELECTION OF  RELEVANT STRUCTURE OR SECTION'/
     1  10X,'LIST OF WEIRS'/
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     1  10X,'(2) ROMIJIN MOVABLE MEASURING/REGULATING WEIR'/
     1  10X,'REF BOS,M.G,DISCHARGE MEASURING STRUCTURE ILRI'/
     1  10X,'NETHEERLAND 1978'/
     1  10X,'(3) TRIANGULAR BROAD-CRESTED WEIR'/
     1  10X,'(4) BROAD-CRESTED RECTANGULAR PROFILE WEIR'/
     1  10X,'(5) FAIYUM WEIR'/
     1  10X,'REF BOS,M.G,DISCHARGE MEASURING STRUCTURE ILRI'/
     1  10X,'NETHEERLAND 1978'/
     1  10X,'(6) RECTANGULAR SHARP-CRESTED WEIR'/
     1  10X,'(7) V-NOTCH SHARP-CRESTED WEIR'/
     1  10X,'(8) CIRCULAR WEIR'/
     1  10X,'(9) PROPORTIONAL WEIR'/)
        PAUSE
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889     FORMAT(10X,'(10)WEIR SILL WITH RECTANGULAR CONTROL SECTION'/
     1  10X,'(11)V-NOTCH WEIR SILL'/
     1  10X,'(12)TRIANGULAR PROFILE TWO-DIMENSION WEIR'/
     1  10X,'(13)TRIANGULAR PROFILE FLAT-VEE WEIR'/
     1  10X,'(14)BUTCHER MOVABLE STANDING WAVE WEIR'/
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     1  10X,'NETHEERLAND 1978'/
     1  10X,'(16)CYLINDRICAL CRESTED WEIR'/
     1  10X,'REF BOS M G DISCHARGE MEASURING STRUCTURE ILRI'/
     1  10X,'NETHEERLAND 1978'/)
        PAUSE
        WRITE(6,886)
886     FORMAT(10X,'LIST OF ORIFICE'/
     1  10X,'(1) RECTANGULAR SHARP-EDGED ORIFICE'/
     1  10X,'(2) RADIAL OR TAINTER GATE'/
     1  10X,'(3) CRUMP-DE GRUYTER ADJUSTABLE ORIFICE'/
```

```
     1  10X,'REF BOS M G DISCHARGE MEASURING STRUCTURE ILRI'/
     1  10X,'NETHEERLAND 1978'/
     1  10X,'(4) METER GATE'/
     1  10X,'(5) NEYRPIC MODULES'/
     1  10X,'REF BOS M G DISCHARGE MEASURING STRUCTURE ILRI'/
     1  10X,'NETHEERLAND 1978'/
     1  10X,'LIST OF FLUMES'/
     1  10X,'(1) LONG THROATED FLUMES'/
     1  10X,'(2) PARSHAL FLUME'/
     1  10X,'(3) H-FLUME'/
     1  10X,'(4) THROATLESS-FLUME'/
     1  10X,'REF BOS M G DISCHARGE MEASURING STRUCTURE ILRI'/
     1  10X,'NETHEERLAND 1978'/)
        PAUSE
C       ****************************************************************
222     WRITE(6,700)
700     FORMAT(10X,'DO YOU WANT DISCHARGE REGULATION ?')
        WRITE(6,702)
702     FORMAT(10X,'YES',' THEN')
        WRITE(6,704)
704     FORMAT(10X,'WRITE  1')
        WRITE(6,706)
706     FORMAT(10X,'IF NOT'/10X,'WRITE  2'/)
        READ(6,*)IPFS
        PAUSE
        WRITE(6,710)
710     FORMAT(10X,'DO YOU WANT TO PASS SEDIMENT OR TRASH ?'/
     1  10X,'YES',' THEN'/10X,'WRITE  3'/
     1  10X,'IF NOT'/10X,'WRITE  4'/)
        READ(6,*)ISED
        PAUSE
        WRITE(6,712)
712     FORMAT(10X,'DO YOU WANT TO PASS TRASH ?'/10X,'YES',' THEN'/
     1  10X,'WRITE  5'/10X,'IF DO NOT'/10X,'WRITE  6'/)
        READ(6,*)ITRS
        PAUSE
        WRITE(6,902)
902     FORMAT(10X,'ENTER Q1MAX  Q1MIN Y1MAX Y1MIN')
        WRITE(6,904)
904     FORMAT(10X,'Q1MAX THE MAXIMUM  DISCHARGE IN CUBIC METERS/SEC'/
     1  10X,'Q1MIN  THE MINIMUM DISCHARGE IN CUBIC METERS/SEC'/
     1  10X,'Y1MAX  THE MAXIMUM DEPTH OF WATER IN METERS'/
     1  10X,'Y1MIN  THE MINIMUM DEPTH OF WATER IN METERS'/)
        READ(6,*)Q1MAX,Q1MIN,Y1MAX,Y1MIN
        PAUSE
        WRITE(6,906)
906     FORMAT(10X,'ENTER P  DHMX  $  B   ')
        WRITE(6,908)
908     FORMAT(10X,'P HEIGHT OF CREST IN METERS'/
     1  10X,'DHMX  MAXIMUM HEAD LOSS IN METERS'/
     1  10X,'B  BREATH OF BOTTOM OF CONTROL SECTION IN METERS'/)
        READ(6,*)P,DHMX,B
        PAUSE
        IF(IPFS.EQ.2)WRITE(6,776)
        IF(IPFS.EQ.1)WRITE(6,775)
```

```
776     FORMAT(10X,'DISCHARGE MEASURING STRUCTRES')
775     FORMAT(10X,'DISCHARGE REGULATING STRUCTURES')
        IF(ISED.EQ.3)WRITE(6,774)
        IF(ISED.EQ.4)WRITE(6,773)
        IF(ITRS.EQ.5)WRITE(6,772)
        IF(ITRS.EQ.6)WRITE(6,771)
774     FORMAT(10X,'SEDIMENT OR TRASH TO BE PASSED')
773     FORMAT(10X,'SEDIMENT OR TRASH NOT TO BE PASSED')
772     FORMAT(10X,'TRASH TO BE PASSED')
771     FORMAT(10X,'TRASH NOT TO BE PASSED')
C       ***************************************************************
C       IN PUT DATA REGISTRATION
        WRITE(6,777)Y1MAX,Y1MIN,Q1MAX,Q1MIN,P,B,DHMX
777     FORMAT(10X,'(1)Y1MAX =',2X,F10.5, 1X,'METERS'
     1  /10X,'(2) Y1MIN =' ,2X,F10.5,1X,'METERS'
     1  /10X,'(3) Q1MAX =' ,2X,F10.5,1X,'CUBIC METER/SEC'
     1  /10X,'(4) Q1MIN =' ,2X,F10.5,1X,'CUBIC METER/SEC'
     1  /10X,'(5)       P =' ,2X,F10.5,1X,'METERS'
     1  /10X,'(6)       B =' ,2X,F10.5,1X,'METERS'
     1  /10X,'(7) DHMX  =' ,2X,F10.5,1X,'METERS'//)
        WRITE(6,111)
111     FORMAT(10X,'ARE YOU SATISFIED WITH INPUT DATA'/
     1  10X,'YES',' THEN'/10X,'WRITE  1'/
     1  10X,'IF NOT'/10X,'WRITE  2'/)
        READ(6,*)SD
        IF(SD.EQ.2) GO TO 222
C       ***************************************************************
        H1MAX=Y1MAX-P
        H1MIN=Y1MIN-P
        GAMA=Q1MAX/Q1MIN
        write(*,*)'GAMA=',GAMA
        QPN=Q1MAX/B
        H2MAX=H1MAX-DHMX
        AML=H2MAX/H1MAX
        IF(H2MAX.LT.0.0001)WRITE(6,770)
        IF(H2MAX.GT.0.0001)WRITE(6,670)
        WRITE(*,200)
200     FORMAT(10x,"DO YOU WANT TO GET RESULT IN A FILE NAMED ",
     1  "SELECT.OUT"/10x,"IF YES THEN WRITE 1"/10x,"OTHERWISE 2")
        READ(*,*)IANS
        IF(IANS.EQ.1)GO TO 201
        GO TO 202
201     WRITE(32,904)
        WRITE(32,908)
        WRITE(32,777)Y1MAX,Y1MIN,Q1MAX,Q1MIN,P,B,DHMX
        IF(IPFS.EQ.2)WRITE(32,776)
        IF(IPFS.EQ.1)WRITE(32,775)
        IF(ISED.EQ.3)WRITE(32,774)
        IF(ISED.EQ.4)WRITE(32,773)
        IF(ITRS.EQ.5)WRITE(32,772)
        IF(ITRS.EQ.6)WRITE(32,771)
        IF(H2MAX.LT.0.0001)WRITE(32,770)
        IF(H2MAX.GT.0.0001)WRITE(32,670)
770     FORMAT(10X,"FREE FLOW CONDITION"//)
670     FORMAT(10X,"SUBMERGED FLOW CONDITION"//)
```

```
202     IF(IPFS.EQ.1)GO TO 6
        IF(IPFS.EQ.2)GO TO 5
5       IF(ISED.EQ.3)GO TO 1234
        IF(ISED.EQ.4)GO TO 1236
1234    CALL SDPS(H1MAX,H2MAX,H1MIN,Q1MAX,Q1MIN,P,B,IANS)
        GO TO 92
1236    CALL SONO(H1MAX,H2MAX,H1MIN,Q1MAX,Q1MIN,GAMA,IANS)
        GO TO 92
6       IF(GAMA.GT.35.0)GO TO 28
        IF(GAMA.LE.35.0)GO TO 29
29      IF(ITRS.EQ.5)GO TO 1235
        IF(ITRS.EQ.6)GO TO 1237
1235    CALL TRPS(H1MAX,H2MAX,Q1MAX,Q1MIN,P,B,ISED,IANS)
        GO TO 92
1237    CALL TRNO(H1MAX,H2MAX,H1MIN,Q1MAX,Q1MIN,P,B,ISED,IANS)
        GO TO 92
28      IF(GAMA.GT.120)GO TO 30
        IF(H1MAX.LT.2.0)GO TO 32
        IF(IANS.EQ.1)GO TO 355
        GO TO 356
355     WRITE(32,59)
356     WRITE(6,59)
59      FORMAT(10X,"THE RELEVANT STRUCTURE IS"/
     1  10X,"CYLINDERICAL CRESTED WEIR"/)
        GO TO 92
32      IF(H1MAX.LT.1.0)GO TO 34
        IF(IANS.EQ.1)GO TO 357
        GO TO 358
357     WRITE(32,61)
        GO TO 92
358     WRITE(6,61)
61      FORMAT(10X,"THE RELEVANT STRUCTURES ARE"/
     1  10X,"(1) CYLINDERICAL CRESTED WEIR"/
     1  10X,"(2) TRIANGULAR PROFILE TWO DIMENSIONAL WEIR"//)
        GO TO 92
34      IF(IANS.EQ.1)GO TO 359
        GO TO 360
359     WRITE(32,63)
360     WRITE(6,63)
63      FORMAT(10X,"THE RELEVANT STRUCTURES ARE"/
     1  10X,"(1) CYLINDERICAL CRESTED WEIR"/
     1  10X,"(2)TRIANGULAR PROFILE TWO DIMENSIONAL WEIR"/
     1  10X,"(3)BUTCHER MOVABLE WEIR"//)
        GO TO 92
30      IF(H1MAX.LT.2.0)GO TO 36
        IF(IANS.EQ.1)GO TO 361
        GO TO 362
361     WRITE(32,65)
362     WRITE(6,65)
65      FORMAT(10X,"THE RELEVANT STRUCTURE IS"/
     1  10X,"CYLINDRICAL CRESTED WEIR WITH TWO OR MORE STRUCTURES"//)
        GO TO 92
36      IF(IANS.EQ.1)GO TO 363
        GO TO 364
363     WRITE(32,67)
```

```
364     WRITE(6,67)
67      FORMAT(10X,"THE RELEVANT STRUCTURES ARE"/
     1  10X,"(1) CYLINDRICAL CRESTED WEIR"/
     1  10X,"(2)TRIANGULAR PROFILE TWO DIMENSIONAL WEIR",
     1  " WITH TWO OR MORE STRUCTURES"//)
92      CONTINUE
        STOP
        END
C       ----------------------------------------------------------------
        SUBROUTINE TRNO(H1MAX,H2MAX,H1MIN,Q1MAX,Q1MIN,P,B,ISED,IANS)
        PAUSE
        WRITE(6,111)
111     FORMAT(10X,'ENTER FLX  FLEXIBILITY'/)
        READ(6,*)FLX
        WRITE(6,555)FLX
555     FORMAT(10X,'(8)FLX=',2X,F4.2)
        IF(IANS.EQ.1)GO TO 201
        GO TO 202
201     WRITE(32,555)FLX
202     IF(FLX.GE.1)GO TO 42
        IF(H1MAX.LT.2.0)GO TO 44
        WRITE(6,69)
        IF(IANS.EQ.1)GO TO 203
        GO TO 94
203     WRITE(32,69)
69      FORMAT(10X,"THE RELEVANT STRUCTURE IS"/
     1  10X,"MOVABLE CYLINDRICAL CRESTED WEIR"//)
        GO TO 94
44      IF(H1MAX.LT.1.0)GO TO 46
        WRITE(6,71)
        IF(IANS.EQ.1)GO TO 300
        GO TO 94
300     WRITE(32,71)
71      FORMAT(10X,"THE RELEVANT STRUCTURES ARE"/
     1  10X,"(1) MOVABLE ROUND NOSE HORIZONTAL BROAD CRESTED WEIR"/
     1  10X,"(2)MOVABLE TRIANGULAR BROAD CRESTED WEIR"/
     1  10X,"(3)MOVABLE CYLINDRICAL CRESTED WEIR"//)
        GO TO 94
46      AML=H2MAX/H1MAX
        IF(AML.LE.0.33)GO TO 48
        WRITE(6,73)
        IF(IANS.EQ.1)GO TO 301
        GO TO 94
301     WRITE(32,73)
73      FORMAT(10X,"THE RELEVANT STRUCTURES ARE"/
     1  10X,"(1) MOVABLE ROUND NOSE HORIZONTAL BROAD CRESTED WEIR,"/
     1  10X,"(2) MOVABLE TRIANGULAR BROAD CRESTED WEIR,"/
     1  10X,"(3) BUTCHER MOVABLE WEIR"//10X,"(4) DIVISORS"//)
        GO TO 94
48      WRITE(6,75)
        IF(IANS.EQ.1)GO TO 302
        GO TO 94
302     WRITE(32,75)
75      FORMAT(10X,"THE RELEVANT STRUCTURES ARE MOVABLE WEIRS"/
     1  10X,"(1)ROUND NOSE HORIZONTAL BROAD CRESTED WEIR,"/
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     1   10X,"(2)RAMIJIN MOVABLE MEASURING OR REGULATING WEIR,"/
     1   10X,"(3)TRIANGULAR BROAD CRESTED WEIR,"/
     1   10X,"(4)BUTCHER MOVABLE WEIR"//)
         GO TO 94
 42      IF(Q1MAX.LT.2.1)GO TO 50
         WRITE(6,77)
         IF(IANS.EQ.1)GO TO 303
         GO TO 94
 303     WRITE(32,77)
 77      FORMAT(10X,"THE RELEVANT STRUCTURE IS"/
     1   10X,"RADIAL OR TAINTER GATE"//)
         GO TO 94
 50      IF(ISED.EQ.3)GO TO 52
         IF(Q1MAX.LT.0.4)GO TO 54
         WRITE(6,79)
         WRITE(32,79)
         IF(IANS.EQ.1)GO TO 304
         GO TO 94
 304     WRITE(32,79)
 79      FORMAT(10X,"THE RELEVANT STRUCTURES ARE"/
     1   10X,"(1)RADIAL OR TAINTER GATE"/
     1   10X,"(2)CRUMP OE GRUYTER ADJUSTABLE ORFICE"/
     1   10X,"(3)METER GATE"//)
         GO TO 94
 52      WRITE(6,81)
         IF(IANS.EQ.1)GO TO 305
         GO TO 94
 305     WRITE(32,81)
 81      FORMAT(10X,"THE RELEVANT STRUCTURES ARE"/
     1   10X,"(1)RADIAL OR TAINTER GATE"/
     1   10X,"(2)RECTANGULAR SHARP EOGED ORIFICE"//)
         GO TO 94
 54      WRITE(6,83)
         IF(IANS.EQ.1)GO TO 306
         GO TO 94
 306     WRITE(32,83)
 83      FORMAT(10X,"THE RELEVANT STRUCTURES ARE"/
     1   10X,"(1)RADIAL OR TAINTER GATE"/
     1   10X,"(2)CRUMP DE GRUYTER ADJUSTABLE ORIFICE"/
     1   10X,"(3)METER GATE"/
     1   10X,"(4)NEYRPIC MODULE"/
     1   10X,"(5)RECTANGULAR SHARP EOGED ORIFICE"//)
         GO TO 94
 94      RETURN
         END
 C       ---------------------------------------------------------------
         SUBROUTINE TRPS(H1MAX,H2MAX,Q1MAX,Q1MIN,P,B,ISED,IANS)
         IF(H1MAX.LT.2.0)GO TO 156
         IF(IANS.EQ.1)GO TO 307
         GO TO 390
 307     WRITE(32,85)
 390     WRITE(6,85)
 85      FORMAT(10X,"THE RELEVANT STRUCTURE IS"/
     1   10X,"CYLINDRICAL CRESTED WEIR"//)
         GO TO 96
```

```
156     CONTINUE
        GO TO 56
56      IF(H1MAX.LT.1.0)GO TO 58
        IF(IANS.EQ.1)GO TO 308
        GO TO 391
308     WRITE(32,87)
391     WRITE(6,87)
87      FORMAT(10X,"THE RELEVANT STRUCTURES ARE"/
     1  10X,"(1)CYLINDRICAL CRESTED WEIR"/
     1  10X,"(2)TRIANGULAR BROAD CRESTED WEIR"/
     1  10X,"(3)ROUND NOSE BROAD CRESTED WEIR"//)
        GO TO 96
58      AML=H2MAX/H1MAX
        WRITE(*,*)'AML=',AML
        IF ((AML.GT.0.3).AND.(AML.LT.0.5))GO TO 60
        IF ((AML.GT.0.5).AND.(AML.LT.0.6))GO TO 62
        IF ((AML.GT.0.6).AND.(AML.LT.0.7))GO TO 64
        IF ((AML.GT.0.7).AND.(AML.LT.0.8))GO TO 66
        IF ((AML.GT.0.8).AND.(AML.LT.0.95))GO TO 68
60      IF(IANS.EQ.1)GO TO 309
        GO TO 392
309     WRITE(32,89)
392     WRITE(6,89)
89      FORMAT(10X,"THE RELEVANT STRUCTURES ARE"/
     1  10X,"ROUND NOSE HORIZONTAL BROAD CRESTED WEIR"/
     1  10X,"THE RAMIJIN MOVABLE MEASURING OR REGULATING WEIR"/
     1  10X,"TRIANGULAR BROAD CRESTED WEIR"/
     1  10X,"BUTCHER MOVABLE WEIR"/10X,"DIVISOR"//)
        GO TO 96
62      IF(IANS.EQ.1)GO TO 310
        GO TO 393
310     WRITE(32,91)
393     WRITE(6,91)
91      FORMAT(10X,"THE RELEVANT STRUCTURES ARE"/
     1  10X,"ROUND NOSE HORIZONTAL BROAD CRESTED WEIR"/
     1  10X,"TRIANGULAR BROAD CRESTED WEIR"/
     1  10X,"BUTCHER MOVABLE WEIR"/10X,"DIVISOR"//)
        GO TO 96
64      IF(IANS.EQ.1)GO TO 311
        GO TO 394
311     WRITE(32,93)
394     WRITE(6,93)
93      FORMAT(10X,"THE RELEVANT STRUCTURES ARE"/
     1  10X,"ROUND NOSE HORIZONTAL BROAD CRESTED WEIR"/
     1  10X,"TRIANGULAR BROAD CRESTED WEIR"/
     1  10X,"BUTCHER MOVABLE WEIR"//)
        GO TO 96
66      IF(IANS.EQ.1)GO TO 312
        GO TO 395
312     WRITE(32,95)
395     WRITE(6,95)
95      FORMAT(10X,"THE RELEVANT STRUCTURES ARE"/
     1  10X,"ROUND NOSE HORIZONTAL BROAD CRESTED WEIR"/
     1  10X,"TRIANGULAR BROAD CRESTED WEIR"//)
        GO TO 96
```

```
60        IF(IANS.EQ.1)GO TO 313
          GO TO 396
313       WRITE(32,97)
396       WRITE(6,97)
97        FORMAT(10X,"THE RELEVANT STRUCTURE IS"/
     1    10X,"ROUND NOSE HORIZONTAL BROAD CRESTED WEIR"//)
          GO TO 96
96        RETURN
          END
C         ----------------------------------------------------------------
          SUBROUTINE SDNO(H1MAX,H2MAX,H1MIN,Q1MAX,Q1MIN,GAMA,IANS)
          WRITE(*,*)'GAMA=',GAMA
          IF(Q1MAX.GE.0.4) GO TO 1111
          IF(Q1MAX.LT.0.4) GO TO 2222
1111      CALL SDPS(H1MAX,H2MAX,H1MIN,Q1MAX,Q1MIN,P,B,IANS)
          GO TO 98
2222      IF(GAMA.LT.56)GO TO 9
          WRITE(6,31)
          IF(IANS.EQ.1)GO TO 314
          GO TO 98
314       WRITE(32,31)
31        FORMAT(10X,"THE RELEVANT STRUCTURES ARE"/
     1    10X,"TRIANGULAR SHARP CRESTED WEIR"/)
          GO TO 98
9         UN=(ALOG(Q1MAX)-ALOG(Q1MIN))/(ALOG(H1MAX)-ALOG(H1MIN))
          WRITE(*,*)'UN=',UN
          IF ((UN .GT. 0.25) .AND. (UN .LE. 0.75)) GO TO 11
          IF ((UN .GT. 0.75) .AND. (UN .LE. 1.25)) GO TO 12
          IF ((UN .GT. 1.25) .AND. (UN .LE. 1.75)) GO TO 13
          IF ((UN .GT. 1.75) .AND. (UN .LE. 2.25)) GO TO 14
          IF (UN .GT. 2.25)  GO TO 15
11        WRITE(6,33)
          IF(IANS.EQ.1)GO TO 315
          GO TO 98
315       WRITE(32,33)
33        FORMAT(10X,"THE RELEVANT STRUCTURES ARE"/
     1    10X,"(1)CIRCULAR SHARP EDGED ORIFIC"/
     1    10X,"(2)RECTANGULAR SHARP EDGED ORIFIC"/
     1    10X,"(3)DANAIDEAN TUB"//)
          GO TO 98
12        WRITE(6,35)
          IF(IANS.EQ.1)GO TO 316
          GO TO 98
316       WRITE(32,35)
35        FORMAT(10X,"THE RELEVANT STRUCTURE IS"/
     1    10X,"PROPORTIONAL WEIR"//)
          GO TO 98
13        WRITE(6,37)
          IF(IANS.EQ.1)GO TO 317
          GO TO 98
317       WRITE(32,37)
37        FORMAT(10X,"THE RELEVANT STRUCTURE IS"/
     1    10X,"RECTANGULAR SHARP CRESTED WIER"//)
          GO TO 98
14        WRITE(6,39)
```

```
      IF(IANS.EQ.1)GO TO 318
      GO TO 98
318   WRITE(32,39)
39    FORMAT(10X,"THE RELEVANT STRUCTURE IS"/
     1 10X,"CIRCULAR WIER"//)
      GO TO 98
15    WRITE(6,41)
      IF(IANS.EQ.1)GO TO 319
      GO TO 98
319   WRITE(32,41)
41    FORMAT(10X,"THE RELEVANT STRUCTURE IS"/
     1 10X,"TRIANGULAR SHARP CRESTED WEIR"//)
      GO TO 98
98    RETURN
      END
C     ------------------------------------------------------------------
      SUBROUTINE SDPS(H1MAX,H2MAX,H1MIN,Q1MAX,Q1MIN,P,B,IANS)
      QPN=(Q1MAX)/B
      WRITE(*,*)'QPN=',QPN
      IF(QPN.LT.6.0) GO TO 16
      WRITE(6,43)
43    FORMAT(10X,"THE RELEVANT STRUCTURES ARE"/
     1 10X,"LARGE CAPACITY SPILLWAYS"/
     1 10X,"(1)WES STANDARD WEIR"/
     1 10X,"(2)CYLINDRICAL CRESTED WEIR"/)
      GO TO 86
16    CALL SUBC(H1MAX,H2MAX,Q1MAX,Q1MIN,P,B,IANS)
      GO TO 321
86    IF(IANS.EQ.1)GO TO 320
      GO TO 321
320   WRITE(32,43)
321   RETURN
      END
C     ------------------------------------------------------------------
      SUBROUTINE SUBC(H1MAX,H2MAX,Q1MAX,Q1MIN,P,B,IANS)
      GAMA=Q1MAX/Q1MIN
      WRITE(*,*)'GAMA=',GAMA
      IF(GAMA.GT.350) GO TO 17
      IF(P.LT.0.01) GO TO 19
      CALL SUBP1(H1MAX,H2MAX,Q1MAX,Q1MIN,P,B,IANS)
      GO TO 88
17    IF(P.LT.0.01) GO TO 18
      CALL SUBP2(H1MAX,H2MAX,Q1MAX,Q1MIN,P,B,IANS)
      GO TO 88
18    IF((Q1MAX.GT.3.3).OR.(H1MAX.GT.1.8))GO TO 20
      WRITE(6,45)
      IF(IANS.EQ.1)GO TO 322
      GO TO 88
322   WRITE(32,45)
45    FORMAT(10X,"THE RELEVANT STRUCTURE IS"/
     1 10X,"H-FLUME"//)
      GO TO 88
19    IF(Q1MAX.LT.3.3) GO TO 21
      WRITE(6,47)
      IF(IANS.EQ.1)GO TO 323
```

```
      GO TO 88
323   WRITE(32,47)
47    FORMAT(10X,"THE RELEVANT STRUCTURES ARE"/
     1 10X,"(1)PARSHAL FLUME"/10X,"(2)LONG THROATED FLUME"//)
      GO TO 88
20    CALL SUBP2(H1MAX,H2MAX,Q1MAX,Q1MIN,P,B,IANS)
      GO TO 88
21    IF(H1MAX.LT.1.36) GO TO 22
      WRITE(6,147)
      IF(IANS.EQ.1)GO TO 324
      GO TO 88
324   WRITE(32,147)
147   FORMAT(10X,"THE RELEVANT STRUCTURES ARE"/
     1 10X,"(1)PARSHAL FLUME"/10X,"(2)LONG THROATED FLUME"//)
      GO TO 88
22    AML=H2MAX/H1MAX
      WRITE(*,*)'AML=',AML
      IF(AML.LT.0.25) GO TO 23
      WRITE(6,247)
      IF(IANS.EQ.1)GO TO 325
      GO TO 88
325   WRITE(32,247)
247   FORMAT(10X,"THE RELEVANT STRUCTURES ARE"/
     1 10X,"(1)PARSHAL FLUME"/10X,"(2)LONG THROATED FLUME"//)
      GO TO 88
23    WRITE(6,49)
      IF(IANS.EQ.1)GO TO 326
      GO TO 88
326   WRITE(32,49)
49    FORMAT(10X,"THE RELEVANT STRUCTURES ARE"/
     1 10X,"(1)WEIR SILL WITH RECTANGULAR CONTROLSECTION"/
     1 10X,"(3)PARSHAL FLUME"/10X,"(4)H-FLUME"//)
      GO TO 88
88    RETURN
      END
C     ----------------------------------------------------------------
      SUBROUTINE SUBP1(H1MAX,H2MAX,Q1MAX,Q1MIN,P,B,IANS)
      GAMA=Q1MAX/Q1MIN
      IF((H2MAX/H1MAX).GT.0.66) GO TO 24
      IF(H1MAX.GT.2.0)GO TO 25
      IF(Q1MIN.LT.0.006)GO TO 26
      IF(GAMA.GT.32)GO TO 27
      WRITE(6,51)
      IF(IANS.EQ.1)GO TO 327
      GO TO 82
327   WRITE(32,51)
51    FORMAT(10X,"THE RELEVANT STRUCTURES ARE"/
     1 10X,"(1)RECTANGULAR CONTROL SECTION WITH"/
     1 10X,"(2)ROUND NOSE HORIZONTAL BROAD CRESTED WEIR"/
     1 10X,"(3)BROAD CRESTED RECTANGULAR PROFILE WEIR"/
     1 10X,"(4)FAIYUM WEIR"/
     1 10X,"(5)TRIANGULAR PROFILE TWO DIMENSION WEIR"/
     1 10X,"(6)CYLINDRICAL CRESTED WEIR"/
     1 10X,"(7)LONG THROATED FLUME"//)
      GO TO 82
24    IF(H1MAX.LT.2.0) GO TO 125
      WRITE(6,52)
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      IF(IANS.EQ.1)GO TO 370
      GO TO 82
370   WRITE(32,52)
52    FORMAT(10X,"THE RELEVANT STRUCTURES  ARE"/
     1 10X,"(1)TRIANGULAR PROFILE TWO DIMENSION WEIR"/
     1 10X,"(2)LONG THROATED FLUME"//)
      GO TO 82
125   IF(Q1MIN.LT.0.006)GO TO 126
      WRITE(6,153)
      IF(IANS.EQ.1)GO TO 328
      GO TO 82
328   WRITE(32,153)
153   FORMAT(10X,"THE RELEVANT STRUCTURES  ARE"/
     1 10X,"(1)ROUNO NOSE HORIZONTAL BROAD CRESTED WEIR"/
     1 10X,"(2)TRIANGULAR BROAD CRESTED WEIR"/
     1 10X,"(3)TRIANGULAR PROFILE TWO OIMENSION WEIR"/
     1 10X,"(4)LONG THROATED FLUME"//)
      GO TO 82
126   WRITE(6,155)
      IF(IANS.EQ.1)GO TO 329
      GO TO 82
329   WRITE(32,155)
155   FORMAT(10X,"THE RELEVANT STRUCTURES  ARE"/
     1 10X,"(2)CYLINDRICAL CRESTED WEIR"/
     1 10X,"(4)LONG THROATED FLUME"//)
      GO TO 82
25    WRITE(6,55)
      IF(IANS.EQ.1)GO TO 330
      GO TO 82
330   WRITE(32,55)
55    FORMAT(10X,"THE RELEVANT STRUCTURES ARE"/
     1 10X,"(1)TRIANGULAR PROFILE FLAT-V-WEIR"/
     1 10X,"(2)LONG THROATED FLUME"/
     1 10X,"(3)CYLINDRICAL CRESTED WEIR"/
     1 10X,"(4)LONG THROATED FLUME"/)
      GO TO 82
26    WRITE(6,157)
      IF(IANS.EQ.1)GO TO 331
      GO TO 82
331   WRITE(32,157)
157   FORMAT(10X,"THE RELEVANT STRUCTURES  ARE"/
     1 10X,"(1)TRIANGULAR BROAD CRESTED WEIR"/
     1 10X,"(2)FAIYUM WEIR"/
     1 10X,"(3)V-NOTCH WEIR SILL"/
     1 10X,"(4)LONG THROATED FLUME"//)
      GO TO 82
27    WRITE(6,57)
      IF(IANS.EQ.1)GO TO 332
      GO TO 82
332   WRITE(32,57)
57    FORMAT(10X,"THE RELEVANT STRUCTURES ARE"/
     1 10X,"(1)TRIANGULAR BROAD CRESTED WEIR"/
     1 10X,"(2)CYLINDRICAL CRESTED WEIR"/
```

```
     1   10X,"(3)FAIYUM WEIR"/
     1   10X,"(4)TRIANGULAR PROFILE FLAT-V-WEIR"/
     1   10X,"(5)LONG THROATED FLUME"/)
         GO TO 82
 82      RETURN
         END
C        ----------------------------------------------------------------
         SUBROUTINE SUBP2(H1MAX,H2MAX,Q1MAX,Q1MIN,P,B,IANS)
         IF(H2MAX/H1MAX.LT.0.66)GO TO 224
         WRITE(6,255)
         IF(IANS.EQ.1)GO TO 333
         GO TO 292
 333     WRITE(32,255)
 255     FORMAT(10X,"THE RELEVANT STRUCTURE IS"/
     1   10X,"TRIANGULAR BROAD CRESTED WEIR"//)
         GO TO 292
 224     IF(H1MAX.LT.2.0)GO TO 226
         WRITE(6,257)
         IF(IANS.EQ.1)GO TO 334
         GO TO 292
 334     WRITE(32,257)
 257     FORMAT(10X,"THE RELEVANT STRUCTURES ARE"/
     1   10X,"TRIANGULAR PROFILE FLAT-V-WEIR"/
     1   10X,"CYLINDRICAL CRESTED WEIR"//)
         GO TO 292
 226     IF(Q1MIN.GT.0.006)GO TO 228
         WRITE(6,259)
         IF(IANS.EQ.1)GO TO 335
         GO TO 292
 335     WRITE(32,259)
 259     FORMAT(10X,"TRIANGULAR BROAD CRESTED WEIR"/
     1   10X,"V-NOTCH WEIR SILL"//)
         GO TO 292
 228     WRITE(6,261)
         IF(IANS.EQ.1)GO TO 336
         GO TO 292
 336     WRITE(32,261)
 261     FORMAT(10X,"THE RELEVANT STRUCTURES ARE"/
     1   10X,"(1)TRIANGULAR BROAD CRESTED WEIR"/
     1   10X,"(2)V-NOTCH WEIR SILL"/
     1   10X,"(3)CYLINDRICAL CRESTED WEIR"//)
         GO TO 292
 292     RETURN
         END
```

SELECTED RELEVANT MEASURING DEVICES BY PROGRAM SELECT FOR A GIVEN INPUT.

EXAMPLE 1

Q1MAX THE MAXIMUM DISCHARGE IN CUBIC METERS/SEC
Q1MIN THE MINIMUM DISCHARGE IN CUBIC METERS/SEC
Y1MAX THE MAXIMUM DEPTH OF WATER IN METERS
Y1MIN THE MINIMUM DEPTH OF WATER IN METERS
P HEIGHT OF CREST IN METERS
DHMX MAXIMUM HEAD LOSS IN METERS
B BREATH OF BOTTOM OF CONTROL SECTION IN METERS

INPUT DATA

(1)Y1MAX = 3.00000 METERS
(2) Y1MIN = 2.40000 METERS
(3) Q1MAX = 3.00000 CUBIC METERS/SEC
(4) Q1MIN = .03000 CUBIC METERS/SEC
(5) P = 1.40000 METERS
(6) B = 2.00000 METERS
(7) DHMX = .60000 METERS

DISCHARGE MEASURING STRUCTRES
SEDIMENT OR TRASH TO BE PASSED
TRASH NOT TO BE PASSED
SUBMERGED FLOW CONDITION

THE RELEVANT STRUCTURES ARE
(1)TRIANGULAR BROAD CRESTED WEIR
(2)CYLINDRICAL CRESTED WEIR
(3)FAIYUM WEIR
(4)TRIANGULAR PROFILE FLAT-V-WEIR
(5)LONG THROATED FLUME

EXAMPLE 2

Q1MAX THE MAXIMUM DISCHARGE IN CUBIC METERS/SEC
Q1MIN THE MINIMUM DISCHARGE IN CUBIC METERS/SEC
Y1MAX THE MAXIMUM DEPTH OF WATER IN METERS
Y1MIN THE MINIMUM DEPTH OF WATER IN METERS
P HEIGHT OF CREST IN METERS
DHMX MAXIMUM HEAD LOSS IN METERS
B BREATH OF BOTTOM OF CONTROL SECTION IN METERS

INPUT DATA

(1)Y1MAX = 2.00000 METERS
(2) Y1MIN = 1.50000 METERS
(3) Q1MAX = .30000 CUBIC METERS/SEC
(4) Q1MIN = .03000 CUBIC METERS/SEC
(5) P = 1.00000 METERS
(6) B = 1.60000 METERS
(7) DHMX = .50000 METERS

DISCHARGE MEASURING STRUCTRES
SEDIMENT OR TRASH NOT TO BE PASSED
TRASH NOT TO BE PASSED
SUBMERGED FLOW CONDITION

THE RELEVANT STRUCTURE IS
TRIANGULAR SHARP CRESTED WEIR

EXAMPLE 3

Q1MAX THE MAXIMUM DISCHARGE IN CUBIC METERS/SEC
Q1MIN THE MINIMUM DISCHARGE IN CUBIC METERS/SEC
Y1MAX THE MAXIMUM DEPTH OF WATER IN METERS
Y1MIN THE MINIMUM DEPTH OF WATER IN METERS
P HEIGHT OF CREST IN METERS
DHMX MAXIMUM HEAD LOSS IN METERS
B BREATH OF BOTTOM OF CONTROL SECTION IN METERS

INPUT DATA

(1)Y1MAX = 2.00000 METERS
(2) Y1MIN = 1.40000 METERS
(3) Q1MAX = 6.00000 CUBIC METERS/SEC
(4) Q1MIN = .30000 CUBIC METERS/SEC
(5) P = 1.20000 METERS
(6) B = 2.00000 METERS
(7) DHMX = .20000 METERS
(8)FLX= .90

DISCHARGE REGULATING STRUCTURES
SEDIMENT OR TRASH NOT TO BE PASSED
TRASH NOT TO BE PASSED
SUBMERGED FLOW CONDITION

THE RELEVANT STRUCTURES ARE
(1) MOVABLE ROUND NOSE HORIZONTAL BROAD CRESTED WEIR,
(2) MOVABLE TRIANGULAR BROAD CRESTED WEIR,
(3) BUTCHER MOVABLE WEIR
(4) DIVISORS

EXAMPLE 4

Q1MAX THE MAXIMUM DISCHARGE IN CUBIC METERS/SEC
Q1MIN THE MINIMUM DISCHARGE IN CUBIC METERS/SEC
Y1MAX THE MAXIMUM DEPTH OF WATER IN METERS
Y1MIN THE MINIMUM DEPTH OF WATER IN METERS
P HEIGHT OF CREST IN METERS
DHMX MAXIMUM HEAD LOSS IN METERS
B BREATH OF BOTTOM OF CONTROL SECTION IN METERS

INPUT DATA

```
(1)Y1MAX =      1.20000 METERS
(2) Y1MIN =      .80000 METERS
(3) Q1MAX =     2.00000 CUBIC METER/SEC
(4) Q1MIN =      .40000 CUBIC METER/SEC
(5)      P =     .50000 METERS
(6)      B =    2.00000 METERS
(7) DHMX  =      .30000 METERS
(8)FLX=  1.20
```

DISCHARGE REGULATING STRUCTURES
SEDIMENT OR TRASH NOT TO BE PASSED
TRASH NOT TO BE PASSED
SUBMERGED FLOW CONDITION

THE RELEVANT STRUCTURES ARE
(1)RADIAL OR TAINTER GATE
(2)CRUMP DE GRUYTER ADJUSTABLE ORFICE
(3)METER GATE

EXAMPLE 5

```
Q1MAX THE MAXIMUM  DISCHARGE IN CUBIC METERS/SEC
Q1MIN  THE MINIMUM DISCHARGE IN CUBIC METERS/SEC
Y1MAX  THE MAXIMUM DEPTH OF WATER IN METERS
Y1MIN  THE MINIMUM DEPTH OF WATER IN METERS
P HEIGHT OF CREST IN METERS
DHMX  MAXIMUM HEAD LOSS IN METERS
B  BREATH OF BOTTOM OF CONTROL SECTION IN METERS
```

INPUT DATA

```
(1)Y1MAX =      1.10000 METERS
(2) Y1MIN =      .80000 METERS
(3) Q1MAX =      .30000 CUBIC METERS/SEC
(4) Q1MIN =      .03000 CUBIC METERS/SEC
(5)      P =     .70000 METERS
(6)      B =    2.00000 METERS
(7) DHMX  =      .40000 METERS
(8)FLX=  1.20
```

DISCHARGE REGULATING STRUCTURES
SEDIMENT OR TRASH NOT TO BE PASSED
TRASH NOT TO BE PASSED
FREE FLOW CONDITION

THE RELEVANT STRUCTURES ARE
(1)RADIAL OR TAINTER GATE
(2)CRUMP DE GRUYTER ADJUSTABLE ORIFICE
(3)METER GATE
(4)NEYRPIC MODULE
(5)RECTANGULAR SHARP EDGED ORIFICE

```
C                     PRGRAM DESIGN
C        A PROGRAM FOR DESIGN OF WEIRS
         REAL K
         INTEGER CN
         OPEN(UNIT=20,FILE='DESIGN.OUT')
         WRITE(6,113)
113      FORMAT(10X,'DESIGN OF WEIRS')
         WRITE(6,115)
115      FORMAT(10X,'LIST OF WEIRS WITH CODE NUMBER'/
     1   10X,'1      LINEAR PROPORTIONAL WEIR'/
     1   10X,'2    . QUADRATIC WEIR'/
     1   10X,'3      LOGRITHMIC WEIR'/
     1   10X,'4      EXPONENTIAL WEIR'/
     1   10X,'5      NEW BASELESS WEIR NBW2'/
     1   10X,'6      WES STANDARD  WEIR'/
     1   10X,'7      ROUND NOSE BROAD CRESTED WEIR'/
     1   10X,'8      ROMJIN MOVABLE WEIR'/
     1   10X,'9      TRIANGULAR BROAD CRESTED WEIR'/
     1   10X,'10     BROAD CRESTED RECTANGULAR WEIR'/)
         WRITE(6,117)
117      FORMAT(10X,'ENTER THE CODE NUMBER DESIRED')
         READ(6,*) CN
         WRITE(6,222)
222      FORMAT(10X,'Q1MAX=MAXIMUM DISCHARGE IN CUBIC METERS/SEC'/
     1   10X,'Q1MIN=MINIMUM DISCHARGE IN CUBIC METERS/SEC'/
     1   10X,'B=WIDTH OF WEIR IN METERS'/
     1   10X,'H1MAX=MAXIMUM HEAD IN METERS'/
     1   10X,'K=PROPORTIONALITY PARAMETER'/
     1   10X,'FL=LENTGH ALONG FLOW DIRECTIONS'/
     1   10X,'YD=DOWN STREAM Y COORDINATE  PROFILE'/
     1   10X,'OF WES-SPILLWAY'/
     1   10X,'YU=DOWN STREAM Y COORDINATE  PROFILE'/
     1   10X,'OF WES-SPILLWAY'/
     1   10X,'X=X COORDINATE OF PROPORTIONAL WEIR'/
     1   10X,'Y=Y COORDINATE OF PROPORTIONAL WEIR'/)
         WRITE(*,310)
10       FORMAT(10X,"DO YOU WANT TO STORE RESULTS IN A FILE NAMED",
     1   " DESIGN.OUT"/10X,"IF YES WRITE 1 OTHERWISE 2")
         READ(*,*)IANS
         IF(IANS.EQ.1)GO TO 375
         GO TO 376
75       WRITE(20,222)
76       IF(CN.EQ.1) GO TO 119
         IF(CN.EQ.2) GO TO 121
         IF(CN.EQ.3) GO TO 123
         IF(CN.EQ.4) GO TO 125
         IF(CN.EQ.5) GO TO 127
         IF(CN.EQ.6) GO TO 129
         IF(CN.EQ.7) GO TO 131
         IF(CN.EQ.8) GO TO 133
         IF(CN.EQ.9) GO TO 135
         IF(CN.EQ.10) GO TO 137
19       CALL SUTRO(IANS)
         GO TO 100
```

```
21    CALL QUADR(IANS)
      GO TO 100
23    CALL LOGT(IANS)
      GO TO 100
25    CALL EXPO(IANS)
      GO TO 100
27    CALL NBW2(IANS)
      GO TO 100
29    CALL WES(IANS)
      GO TO 100
31    CALL RNBW(IANS)
      GO TO 100
33    CALL RMW(IANS)
      GO TO 100
35    CALL TBW(IANS)
      GO TO 100
37    CALL BCR(IANS)
      GO TO 100
10    STOP
      END
```

```
      SUBROUTINE SUTRO(IANS)
      REAL K
      WRITE (6,100)
10    FORMAT(10X,'WELCOME TO THE DESIGN OF'/
    1 10X,'LINEAR PROPORTIONAL WEIR'/)
      PAUSE
      WRITE(6,111)
 1    FORMAT(10X,'ENTER THE VALUE Q1MAX,Q1MIN,Y1MAX,B,DY')
      READ(6,*)Q1MAX,Q1MIN,Y1MAX,B,DY
      G=9.81
      CD=0.63
      A=(Q1MIN/(CD*2./3.*(2.*G)**0.5*B))**(2./3.)
      WRITE(*,*)A
      K=CD*B*(2.0*G*A)**0.5
      WRITE(*,*)K
      H1MAX=Q1MAX/K+A/3.
      P=Y1MAX-H1MAX
      WRITE(6,*)'--- INPUT DATA ------------'
      WRITE(6,133)Q1MAX,Q1MIN,B,Y1MAX,CD,G
133   FORMAT(1X,'Q1MAX=',F10.4,2X,'Q1MIN=',F10.4,2X,'B=',F10.4,
    1 2x,'Y1MAX=',F10.4,2X,'CD=',F10.4,2X,'G=',F10.4/)
      IF(IANS.EQ.1)GO TO 311
      GO TO 312
11    WRITE(20,*)'--- INPUT DATA ------------'
      WRITE(20,133)Q1MAX,Q1MIN,B,Y1MAX,CD,G
      WRITE(20,*)'------- OUTPUT FOLLOWS---'
      WRITE(20,200)A,K,H1MAX,P
12    WRITE(6,*)'------- OUTPUT FOLLOWS---'
      WRITE(6,200)A,K,H1MAX,P
00    FORMAT(1X,'A=',F10.4,2X,'K=',F12.5,2X,'H1MAX=',F12.5
    1 ,2X,'P='F10.4/)
      Y=0.0
0     Y=Y+DY
      X=0.5*B*(1.0 -2.0 / 3.1415927*ATAN(SQRT(Y/A)))
      IF(Y.GT.H1MAX) GO TO 20
      WRITE(6,105) Y,X
```

```
      IF(IANS.EQ.1)GO TO 313
      GO TO 314
13    WRITE(20,105) Y,X
05    FORMAT(5X,'Y=',F12.5,2X,'X=',F12.5/)
14    GO TO 10
0     RETURN
      END
      ------------------------------------------------------------------
      SUBROUTINE QUADR(IANS)
      WRITE (6,100)
00    FORMAT(10X,'WELCOME FOR DESIGN OF'/
    1 10X,'QUADRATIC WEIR '/)
      PAUSE
      WRITE(6,111)
11    FORMAT(10X,'ENTER THE VALUE Q1MAX,Q1MIN,Y1MAX,B,DY')
      READ(6,*)Q1MAX,Q1MIN,Y1MAX,B,DY
      G=9.81
      CD=0.63
      A=(Q1MIN/(2./3.*CD*(2.*G)**0.5*B))**(2./3.)
      K=CD*B*(2.0*G*A)**0.5
      FK=1.1547*CD*B*A*((2.0*G)**0.5)
      H1MAX=(Q1MAX/FK)**2+2.*A/3.0
      P=Y1MAX-H1MAX
      H0=H1MAX-A
      WRITE(6,*)'--- INPUT DATA -----------'
      WRITE(6,133)Q1MAX,Q1MIN,B,Y1MAX,CD,G
133   FORMAT(1X,'Q1MAX=',F10.4,2X,'Q1MIN=',F10.4,2X,'B=',F10.4
    1 ,2x,'Y1MAX=',F10.4,2X,'CD=',F10.4,2X,'G=',F10.4/)
      IF(IANS.EQ.1)GO TO 315
      GO TO 316
15    WRITE(20,*)'--- INPUT DATA -----------'
      WRITE(20,133)Q1MAX,Q1MIN,B,Y1MAX,CD,G
      WRITE(20,*)'------- OUTPUT FOLLOWS---'
      WRITE(20,200)A,FK,H1MAX,P
16    WRITE(6,*)'------- OUTPUT FOLLOWS---'
      WRITE(6,200)A,FK,H1MAX,P
00    FORMAT(1X,'A=',F10.4,2X,'FK=',F12.5,2X,'H1MAX=',F12.5
    1 ,2X,'P='F10.4/)
      Y=0.0
)     Y=Y+DY
      D=(1.0-2.0/3.1415927*ATAN(SQRT(Y/A)))
      E=6./3.1415927*SQRT(Y/A)/(1.+3.*Y/A)
      X=0.5*B*(D-E)
      IF(Y.GT.H1MAX) GO TO 20
      WRITE(6,105) Y,X
      IF(IANS.EQ.1)GO TO 317
      GO TO 318
7     WRITE(20,105) Y,X
5     FORMAT(5X,'Y=',F12.5,2X,'X=',F12.5/)
8     GO TO 10
      RETURN
      END
      ------------------------------------------------------------------
```

```
      SUBROUTINE LOGT(IANS)
      REAL K
      WRITE (6,100)
100   FORMAT(10X,'WELCOME TO THE DESIGN OF'/
     1 10X,'LOGRITHMIC WEIR '/)
      PAUSE
      WRITE(6,111)
111   FORMAT(10X,'ENTER THE VALUE Q1MAX,Q1MIN,Y1MAX,B,DY')
      READ(6,*)Q1MAX,Q1MIN,Y1MAX,B,DY
      G=9.81
      CD=0.63
      A=(Q1MIN/CD*2./3.*(2.*G)**.5*B)**(2./3.)
      FFN=.5
102   FFN=0.5+0.1
      CALL NRF(SG,FFN)
      WRITE(*,*)SG
      K=Q1MIN/ALOG(SG)
      WRITE(*,*)Q1MIN
      H0=(EXP(Q1MAX/K)-SG)*FFN*A
      H1MAX=H0+A
      WRITE(*,*)H1MAX
      IF(H1MAX.LT.Y1MAX) GO TO 102
      P=Y1MAX-H1MAX
      WRITE(6,*)'--- INPUT DATA ------------'
      WRITE(6,133)Q1MAX,Q1MIN,B,Y1MAX,CD,G
133   FORMAT(1X,'Q1MAX=',F10.4,2X,'Q1MIN=',F10.4,2X,'B=',F10.4
     1 ,2x,'Y1MAX=',F10.4,2X,'CD=',F10.4,2X,'G=',F10.4/)
      IF(IANS.EQ.1)GO TO 319
      GO TO 320
319   WRITE(20,*)'--- INPUT DATA ------------'
      WRITE(20,133)Q1MAX,Q1MIN,B,Y1MAX,CD,G
      WRITE(20,200)A,K,H1MAX,P
320   WRITE(6,*)'------- OUTPUT FOLLOWS---'
      WRITE(6,200)A,K,H1MAX,P
200   FORMAT(1X,'A=',F10.4,2X,'K=',F12.5,2X,'H1MAX=',F12.5
     1 ,2X,'P='F10.4/)
C     ----------------------------------------------------------
      Y=0.0
30    Y=Y+DY
      E=1.-2./3.14*ATAN(SQRT(Y/A))
      BF=2./3.14*(SQRT(Y/A))/(SG*FFN+Y/A)
      BG=((SG*FFN+Y/A)**.5+(Y/A)**.5)
      BH=((SG*FFN+Y/A)**0.5-(Y/A)**.5)
      H=BG/BH
      AG=SG*FFN/(3.14*(SG*FFN+Y/A))**1.5*ALOG(H)
      X=0.5*B*(E-BF-AG)
      IF(X.LT.0.0) GO TO 20
      WRITE(6,105) Y,X
      IF(IANS.EQ.1)GO TO 321
      GO TO 322
321   WRITE(20,105) Y,X
105   FORMAT(5X,'Y=',F12.5,2X,'X=',F12.5/)
322   GO TO 30
20    RETURN
      END
```

```
C       ----------------------------------------------------------------
        SUBROUTINE NRF(SG,FN)
        SG=5.0
370     FT=(2.0/3.0)/(SG*FN)
        FX=SG-EXP(FT)
        DFX=1.0+(FT/SG)*EXP(FT)
        SG1=SG-FX/DFX
        IF(ABS(SG1-SG).LE.0.0005)GO TO 300
        SG=SG1
        GO TO 370
300     RETURN
        END
C       ----------------------------------------------------------------
C       EXPONENTIAL  WEIR
        SUBROUTINE EXPO(IANS)
        REAL K
        WRITE (6,100)
100     FORMAT(10X,'WELCOME TO THE DESIGN OF'/
     1  10X,'EXPONENTIAL WEIR'/)
        PAUSE
        WRITE(6,111)
111     FORMAT(10X,'ENTER THE VALUE Q1MAX,Q1MIN,Y1MAX,B,CD,DY')
        READ(6,*)Q1MAX,Q1MIN,Y1MAX,B,CD,DY
        FLEM=1.5
        G=9.81
        A=(Q1MIN/CD*2./3.*(2.*G)**.5*B)**(2./3.)
        H0=A/FLEM*ALOG(Q1MAX/Q1MIN)
        H1MAX=H0+A
        P=Y1MAX-H1MAX
        WRITE(6,*)'--- INPUT DATA ------------'
        WRITE(6,133)Q1MAX,Q1MIN,B,Y1MAX,CD,G
133     FORMAT(1X,'Q1MAX=',F10.4,2X,'Q1MIN=',F10.4,2X,'B=',F10.4
     1  ,2X,'Y1MAX=',F10.4,2X,'CD=',F10.4,2X,'G=',F10.4/)
        IF(IANS.EQ.1)GO TO 323
        GO TO 324
323     WRITE(20,*)'--- INPUT DATA ------------'
        WRITE(20,133)Q1MAX,Q1MIN,B,Y1MAX,CD,G
        WRITE(20,*)'------- OUTPUT FOLLOWS---'
        WRITE(20,200)A,H0,H1MAX,P
324     WRITE(6,*)'------- OUTPUT FOLLOWS---'
        WRITE(6,200)A,H0,H1MAX,P
200     FORMAT(1X,'A=',F10.4,2X,'H0=',F12.5,2X,'H1MAX=',F12.5
     1  ,2X,'P='F10.4/)
        Y=0.0
40      Y=Y+DY
        IF(Y.GT.H1MAX) GO TO 50
        OM=SQRT(Y*FLEM)
        CALL ERR(OM,TRAP)
C       ________________________________________________________
        E=1.-2./3.14*ATAN(SQRT(Y/A))
        H=2.0*Q1MIN*FLEM**1.5*EXP(FLEM*Y)/(CD*(2*9.81)**.5)*TRAP
        X=0.5*B*E+H
        TYPE *,H,Y,OM,TRAP
        WRITE(6,105) Y,X
        IF(IANS.EQ.1)GO TO 325
```

```
      GO TO 326
325   WRITE(20,105) Y,X
105   FORMAT(5X,'Y=',F12.5,2X,'X=',F12.5/)
326   GO TO 40
50    RETURN
      END
C     ________________________________________________
      SUBROUTINE ERR(B,TRAP)
C     PROGRAM TRPEZOIDAL
C     PROGRAM TO EVALUATE THE INTEGRAL OF EXP(X**-2.)
C     BETBEEN THE LIMITS A TO B
C     RULE OF INTEGRATION BASED ON N SUBINTERVALS
C     OR N+1 NODAL POINTS.THE VALUE OF A,B, AND N
C     ARE TO BE READ AND THE ITEGRAND IS WRITTEN
C     AS A FUNCTION OFSUBPROGRAM
C     ________________________________________________________
      A=0.0
      N=17
      DX=(B-A)/N
      SUM=0.0
      M=N-1
      DO 20 I=1,M
      X=A+I*DX
      SUM=SUM+F(X)
 20   CONTINUE
      TRAP=0.5*DX*(F(A)+F(B)+2.*SUM)
      RETURN
      END
C     ________________________________________________________
      FUNCTION F(X)
      F=1./EXP(X**2.)
      RETURN
      END
C     -----------------------------------------------------
C     BASELESS  WEIR (NBW2)
      SUBROUTINE NBW2(IANS)
      REAL K
      WRITE (6,100)
100   FORMAT(10X,'WELCOME TO THE DESIGN OF'/
    1 10X,'BASELESS WEIR (NBW2)'/)
      PAUSE
      WRITE(6,111)
111   FORMAT(10X,'ENTER THE VALUE Q1MAX,H1MAX,Y1MAX,T,CD,DY')
      READ(6,*)Q1MAX,H1MAX,Y1MAX,T,CD,DY
      G=9.81
      AP=SQRT(H1MAX)*ALOG(1.+H1MAX/T)
      K=Q1MAX/AP
      R=3.1415*CD*(SQRT(2.0*G))*T
      BW=K/R
      WRITE(6,*)'--- INPUT DATA ------------'
      WRITE(6,133)Q1MAX,H1MAX,T,CD,DY
 133  FORMAT(1X,'Q1MAX=',F10.4,2X,'H1MAX=',F10.4,2X,'T=',F10.4
     1,2X,'CD=',F10.4,2X,'DY=',F10.4/)
      write(*,*)BW
      IF(IANS.EQ.1)GO TO 327
```

```
      GO TO 328
327   WRITE(20,*)'--- INPUT DATA ------------'
      WRITE(20,133)Q1MAX,H1MAX,T,CD,DY
      WRITE(20,*)'------- OUTPUT FOLLOWS---'
328   WRITE(6,*)'------- OUTPUT FOLLOWS---'
C     ____________________________________________________________
      Y=0.0
40    Y=Y+DY
      IF(Y.GT.H1MAX)GO TO 50
      CALL INTEG(Y,T,TRAP)
C     ____________________________________________________
      X=BW*TRAP
      WRITE(6,105) Y,X
      IF(IANS.EQ.1)GO TO 329
      GO TO 330
329   WRITE(20,105) Y,X
105   FORMAT(5X,'Y=',F12.5,2X,'X=',F12.5/)
330   GO TO 40
50    RETURN
      END
C     ____________________________________________________
      SUBROUTINE INTEG(Y,T,TRAP)
C     PROGRAM TRPEZOIDAL
C     PROGRAM TO EVALUATE THE INTEGRAL
C     BETBEEN THE LIMITS A TO B
C     RULE OF INTEGRATION BASED ON N SUBINTERVALS
C     OR N+1 NODAL POINTS.THE VALUE OF A,B, AND N
C     ARE TO BE READ AND THE ITEGRAND IS WRITTEN
C     AS A FUNCTION OFSUBPROGRAM
C     ________________________________________________________
      A=-0.5
      B=0.49999
      N=33
      DX=(B-A)/N
      SUM=0.0
      M=N-1
      DO 20 I=1,M
      U=A+I*DX
      SUM=SUM+FF(U,T,Y)
 20   CONTINUE
      TRAP=0.5*DX*(FF(A,T,Y)+FF(B,T,Y)+2.*SUM)
      RETURN
      END
C     ________________________________________________________
      FUNCTION FF(U,T,Y)
      FF=SQRT((U+0.5)/(0.5-U))*(1.0/((Y/T)*(U+0.5)+1.0)**2.0+
     1 0.5/((Y/T)*(U+0.5)+1.0))
      RETURN
      END
C     ****************************************************************
C     WES-STANDARD SPILLWAY
      SUBROUTINE WES(IANS)
      WRITE (6,100)
100   FORMAT(10X,'WELCOME TO THE DESIGN OF'/
     1 10X,'WES-STANDARD SPILLWAY '/)
```

```
      PAUSE
      WRITE(6,101)
101   FORMAT(10X,'ENTER Q1MAX,Q1MIN,B,Y1MAX'/)
      READ(5,*)Q1MAX,Q1MIN,B,Y1MAX
      WRITE(6,38)Q1MAX,Q1MIN,B,Y1MAX
38    FORMAT(10X,'________INPUT DATA_______________'/
     1 10X,'MAXIMUM DISCHARGE Q1MAX=',F10.4,2X,'CUBIC METERS'/
     1 10X,'MINIMUM DISCHARGE Q1MIN=',F10.4,2X,'CUBIC METERS'/
     1 10X,'BREATH OF WEIR B=',F10.4,2X,'METERS'/
     1 10X,'MAXIMUM DEPTH OF WATER Y1MAX=',F10.4,2X,'METERS'/)
      WRITE(6,102)
102   FORMAT(10X,'ENTER TRIAL VALUE OF H1MAX'/)
      READ(5,*)H1MAX
      DO 111 I=1,10
      QBMAX=Q1MAX/B
      QBMIN=Q1MIN/B
      VA=QBMAX/Y1MAX
      HA=(VA**2.0)/(2.0*9.81)
      EN=Y1MAX+HA
      P=EN-HDMAX
      PHD=P/HDMAX
C     IF((PHD.GT.0.05).AND.(PHD.LE.0.25))GO TO 401
      IF((PHD.GT.0.25).AND.(PHD.LE.0.50))GO TO 403
      IF((PHD.GT.0.50).AND.(PHD.LE.1.00))GO TO 405
      IF((PHD.GT.1.00).AND.(PHD.LE.1.50))GO TO 407
      IF((PHD.GT.1.50).AND.(PHD.LE.3.00))GO TO 409
      IF(PHD.GT.3.00)GO TO 411
401   CDO=0.63+0.25*(PHD-0.05)
403   CDO=0.68+0.12*(PHD-0.25)
405   CDO=0.71+0.03*(PHD-0.5)
407   CDO=0.725+0.01*(PHD-1.0)
409   CDO=0.73+0.0053*(PHD-1.5)
411   CDO=0.738
      FK1=2.0/3.0
      FK2=(2.0*9.81)**0.5
      U=1.5
      FU=1.0/U
      HDMAX=(QBMAX/(CDO*FK1*FK2))**FU
      H1MAX=HDMAX-VA
      P=Y1MAX-H1MAX
111   CONTINUE
      HA=(VA**2.0)/(2.0*9.81)
      H1MIN=(QBMIN/(CDO*FK1*FK2))**FU
      P=Y1MAX-H1MAX
      WRITE(6,48)
48    FORMAT(10X,'__________DESIGN PARAMETER______________')
      WRITE(6,104)P,H1MAX,H1MIN
104   FORMAT(10X,'HEIGHT OF CREST ABOVE APPROACH CHANNEL BED P'/
     1 10X,'IN METERS'/
     1 10X,'DESIGN HEAD ABOVE CREST OF WEIR H1MAX'/
     1 10X,'MINIMUM HEAD ABOVE CREST OF WEIR H1MIN'/
     1 10X,' P='F10.4/10X,'H1MAX='F10.4/10X,'H1MIN='F10.4/)
      IF(IANS.EQ.1)GO TO 331
      GO TO 332
331   WRITE(20,38)Q1MAX,Q1MIN,B,Y1MAX
      WRITE(20,48)
```

```
      WRITE(20,104)P,H1MAX,H1MIN
      WRITE(20,*)'------- OUTPUT FOLLOWS---'
332   WRITE(6,*)'------- OUTPUT FOLLOWS---'
      X=0.00
      DX=0.1
502   XH=X/HDMAX
      YD=HDMAX*0.5*(XH)**1.85
      WRITE(6, 566) X, YD
      IF(IANS.EQ.1)GO TO 333
      GO TO 334
333   WRITE(20, 566) X, YD
566   FORMAT(10X,'X=',F10.5,2X,'YD=',F10.5)
334   X=X+DX
      A5=P
      IF(YD.GT.A5) GO TO 501
      GO TO 502
501   X=.00
      DX=0.1
504   XH=X/HDMAX
      YU=HDMAX*(0.724*(XH+0.27)**1.85-
     1 .432*(XH+.27)**0.623+.126)
      WRITE(6, 567) X, YU
      IF(IANS.EQ.1)GO TO 335
      GO TO 336
335   WRITE(20, 567) X, YU
567   FORMAT(10X,'X=',F10.5,2X,'YU=',F10.5)
336   X=X+DX
      B5=0.270*HDMAX
      IF(YU.GT.B5)GO TO 503
      GO TO 504
503   RETURN
      END

C     ____________________________________________________________
C     ROUND NOSE HORIZONTAL BROAD CRESTED WEIR
      SUBROUTINE RNBW(IANS)
      WRITE(6,100)
100   FORMAT(10X,'WELCOME TO THE  DESIGN OF '/
     1 10X,'ROUND NOSE HORIZONTAL BROAD CRESTED WEIR'/)
      WRITE(6,32)
32    FORMAT(10X,'ENTER Q1MAX,Q1MIN,B,FL,Y1MAX'/)
      READ(6,*)Q1MAX,Q1MIN,B,FL,Y1MAX
      PAUSE
      WRITE(6,33)
33    FORMAT(10X,'ENTER TRIAL VALUE OF H1MAX'/)
      READ(6,*)H1MAX
      WRITE(6,38)Q1MAX,Q1MIN,B,FL,Y1MAX


38    FORMAT(10X,'________INPUT DATA_______________'/
     1 10X,'MAXIMUM DISCHARGE Q1MAX=',F10.4,2X,'CUBIC METERS'/
```

```
     1  10X,'MINIMUM DISCHARGE ...
     1  10X,'BREATH OF WEIR B=',F10.4,2X,'METERS'/
     1  10X,'MAXIMUM DEPTH OF WATER Y1MAX=',F10.4,2X,'METERS'/)
        X=0.003
        U=1.5
        BM=0.5*B
        FK1=2.0/3.0
        FK2=(FK1*9.81)**0.5
        DO 111 I=1,10
        R=0.2*H1MAX
        CD=(1-2.0*X*(FL-R)/BM)*(1.0-X*(FL-R)/H1MAX)**1.5
        A=B*Y1MAX
        VH=(Q1MAX/A)**2.0/(2.0*9.81)
        HEMX1=H1MAX+VH
        CV=(HEMX1/H1MAX)**U
        H1MAX=(Q1MAX/(CD*CV*FK1*FK2*BM))**0.6666
111     CONTINUE
        WRITE(6,48)
48      FORMAT(10X,'__________DESIGN PARAMETER_____________')
        WRITE(6,104)P,H1MAX
104     FORMAT(10X,'HEIGHT OF CREST ABOVE APPROACH CHANNEL BED P'/
     1  10X,'IN METERS'/
     1  10X,'DESIGN HEAD ABOVE CREST OF WEIR H1MAX'/
     1  10X,'MINIMUM HEAD ABOVE CREST OF WEIR H1MIN'/
     1  10X,' P='F10.4/10X,'H1MAX='F10.4/10X/)
        P=Y1MAX-H1MAX
        H1MIN=0.2
        DO  1111 I=1,5
        R=0.2*H1MIN
        CD=(1-2.0*X*(FL-R)/BM)*(1.0-X*(FL-R)/H1MIN)**1.5
        Q1MIN=1.0
        H1MIN=(Q1MIN/(CD*FK1*FK2*BM))**0.66666
1111    CONTINUE
        WRITE (6,35) H1MIN
35      FORMAT(10X,'H1MIN=',F10.4)
        WRITE(6,41)
41      FORMAT(10X,'LIMITATION OF ROUND NOSE BROAD CRESTED WEIR'/
     1  10X,'H1MAX>0.06'/10X,'H1MAX>0.05*FL'/
     1  10X,'P>0.15 METER'/10X,'H1MAX/P<3.0'/
     1  10X,'0.05<(H1MAX/FL))0.5'/10X,'B>0.3'/
     1  10X,'B>H1MAX'/10X,'B>0.2*FL'/)
        IF(IANS.EQ.1)GO TO 339
        GO TO 340
339     WRITE(20,38)Q1MAX,Q1MIN,B,FL,Y1MAX
        WRITE(20,48)
        WRITE(6,104)P,H1MAX
        WRITE (20,35) H1MIN
        WRITE(6,41)
340     RETURN
        END
C       ____________________________________________________________
C       ROMJIN MOVABLE WEIR
        SUBROUTINE RMW(IANS)
        WRITE (6,100)
100     FORMAT(10X,'WELCOME TO THE  DESIGN OF'/
     1  10X,'ROMJIN MOVABLE WEIR '/)
        PAUSE
        WRITE(6,1032)
1032    FORMAT(10X,'Q1MAX,Q1MIN,Y1MAX,FL,B'/)
```

```
      READ(5,*)Q1MAX,Q1MIN,Y1MAX,FL,B
      PAUSE
      WRITE(6,38)Q1MAX,Q1MIN,B,Y1MAX
38    FORMAT(10X,'________IN PUT DATA________________'/
     1 10X,'MAXIMUM DISCHARGE Q1MAX=',F10.4,2X,'CUBIC METERS'/
     1 10X,'MINIMUM DISCHARGE Q1MIN=',F10.4,2X,'CUBIC METERS'/
     1 10X,'BREATH OF WEIR B=',F10.4,2X,'METERS'/
     1 10X,'MAXIMUM DEPTH OF WATER Y1MAX=',F10.4,2X,'METERS'/)
      WRITE(6,1036)
1036  FORMAT(10X,'ENTER TRIAL VALUE OF H1MAX')
      READ(5,*)H1MAX
      DO 111 I=1,10
      CD=1.0
      A=B*Y1MAX
      VH=(Q1MAX/A)**2.0/(2.0*9.81)
      HEMX1=H1MAX+VH
      U=1.5
      CV=(HEMX1/H1MAX)**U
      FK1=2.0/3.0
      FK2=(FK1*9.81)**0.5
      H1MAX=(Q1MAX/(CD*CV*FK1*FK2*BM))**0.6666
      H1MIN=(Q1MIN/(CD*CV*FK1*FK2*BM))**0.6666
111   CONTINUE
      WRITE(6,48)
      WRITE(20,48)
48    FORMAT(10X,'__________DESIGN PARAMETER______________')
      WRITE(6,104)P,H1MAX,H1MIN
104   FORMAT(10X,'HEIGHT OF CREST ABOVE APPROACH CHANNEL BED P'/
     1 10X,'IN METERS'/
     1 10X,'MAXIMUM HEAD ABOVE CREST OF WEIR H1MIN IN METERS'/
     1 10X,'MINIMUM HEAD ABOVE CREST OF WEIR H1MIN IN METERS'/
     1 10X,' P='F10.4/10X,'H1MAX='F10.4/10X,'H1MIN='F10.4/)
342   RETURN
      END
C     ****************************************************************
C     TRIANGULAR BROAD CRESTED WEIR
      SUBROUTINE TBW(IANS)
      WRITE (6,100)
100   FORMAT(10X,'WELCOME TO THE DESIGN OF'/
     1 10X,'TRIANGULAR BROAD CRESTED WEIR'/)
      PAUSE
      WRITE(6,1132)
1132  FORMAT(10X,'Q1MAX,Q1MIN,Y1MAX,B,ANG,FL'/)
      READ(6,*)Q1MAX,Q1MIN,Y1MAX,B,ANG,FL
      WRITE(6,1136)


1136  FORMAT(10X,'ENTER TRIAL VALUE OF H1MAX')
      READ(6,*)H1MAX
      U=2.5
      P=1.0
      FU=1.0/U
      A=B*Y1MAX
```

```
      DO 111 I=1,5
      AL=H1MAX/FL
      IF((AL.GT.0.06).AND.(AL.LE.0.1))GO TO 410
      IF((AL.GT.0.10).AND.(AL.LE.0.15))GO TO 412
      IF((AL.GT.0.15).AND.(AL.LE.0.2))GO TO 414
      IF((AL.GT.0.20).AND.(AL.LE.0.3))GO TO 416
      IF(AL.GT.0.30)GO TO 418
410   AHL=AL-0.06
      CD=0.85+1.30*AHL
412   AHL=AL-0.10
      CD=0.902+0.64*AHL
414   AHL=AL-0.15
      CD=0.932+0.32*AHL
416   AHL=AL-0.2
      CD=0.948+0.15*AHL
418   AHL=AL-0.3
      CD=0.963+0.1*AHL
      HB=0.5*BM
      HEMX1=H1MAX+VH
      WRITE(*,*)'HEMX1',HEMX1
      CV=(HEMX1/H1MAX)**U
      FK1=0.800
      FK2=(0.4*9.81)**0.5
      THETA=(3.14*ANG)/180.0
      FK3=TAN(THETA)
      H1MAX=(Q1MAX/(CD*CV*FK1*FK2*FK3))**FU
      H1MIN=(Q1MIN/(CD*CV*FK1*FK2*FK3))**FU
34    FORMAT(10X,'H1MAX=',F10.5)
111   CONTINUE
      P=Y1MAX-H1MAX
      WRITE(6,48)
      WRITE(20,48)
48    FORMAT(10X,'__________DESIGN PARAMETER______________')
      WRITE(6,104)P,H1MAX,H1MIN
104   FORMAT(10X,'HEIGHT OF CREST ABOVE APPROACH CHANNEL BED P'/
     1 10X,'IN METERS'/
     1 10X,'DESIGN HEAD ABOVE CREST OF WEIR H1MAX'/
     1 10X,'MINIMUM HEAD ABOVE CREST OF WEIR H1MIN'/
     1 10X,' P='F10.4/10X,'H1MAX='F10.4/10X,'H1MIN='F10.4/)
      IF(IANS.EQ.1)GO TO 343
      GO TO 344
343   WRITE(20,345)Q1MAX,Q1MIN,Y1MAX,B,ANG
345   FORMAT(10X,'----------INPUT DATA-----------'/10X,
     1 10X,'MAXIMUM DISCHARGE Q1MAX=',F10.4,2X,'CUBIC METERS'/
     1 10X,'MINIMUM DISCHARGE Q1MIN=',F10.4,2X,'CUBIC METERS'/
     1 10X,'MAXIMUM DEPTH OF WATER Y1MAX=',F10.4,2X,'METERS'/
     1 10X,'BREATH OF WEIR B=',F10.4,2X,'METERS'/10X,'ANGLE= ',F5.2/)
      WRITE(20,48)
      WRITE(6,104)P,H1MAX,H1MIN


344   RETURN
```

```
C
C       BROAD CRESTED RECTANGULAR PROFILE WEIR
        SUBROUTINE BCR(IANS)
        WRITE (6,100)
100     FORMAT(10X,'WELCOME TO THE DESIGN OF BROAD CRESTED'/
      1 10X,'RECTANGULAR PROFILE WEIR'/)
        PAUSE
        WRITE(6,101)
101     FORMAT(10X,'ENTER Q1MAX,Q1MIN,B,Y1MAX,FL',/)
        READ(5,*)Q1MAX,Q1MIN,B,Y1MAX,FL
        WRITE(6,380)Q1MAX,Q1MIN,B,Y1MAX
380     FORMAT(10X,'________IN PUT DATA_______________'/
      1 10X,'MAXIMUM DISCHARGE Q1MAX=',F10.4,2X,'CUBIC METERS'/
      1 10X,'MINIMUM DISCHARGE Q1MIN=',F10.4,2X,'CUBIC METERS'/
      1 10X,'BREATH OF WEIR B=',F10.4,2X,'METERS'/
      1 10X,'MAXIMUM DEPTH OF WATER Y1MAX=',F10.4,2X,'METERS'/)
        WRITE(6,102)
102     FORMAT(10X,'ENTER TRIAL VALUE OF H1MAX'/)
        READ(5,*)H1MAX
        U=1.5
        DO 111 I=1,10
        P=Y1MAX-H1MAX
        AFL=H1MAX/FL
        APL=H1MAX/(H1MAX+P)
        IF(APL.LE.0.35)GO TO 21
        IF((APL.GT.0.35).AND.(APL.LE.0.40))GO TO 22
        IF((APL.GT.0.40).AND.(APL.LE.0.50))GO TO 24
        IF((APL.GT.0.50).AND.(APL.LE.0.55))GO TO 26
        IF(APL.GT.0.55)GO TO 27
21      IF(AFL.LE.0.4)GO TO 28
        IF(AFL.GT.0.4)GO TO 30
28      F=1.0
        GO TO 50
30      F=1.0+(0.24/1.1)*(AFL-0.4)
        GO TO 50
22      IF(AFL.LE.0.35)GO TO 32
        IF(AFL.GT.0.35)GO TO 34
32      F=1.01
        GO TO 50
34      F=1.01+.16*(AFL-0.35)
        GO TO 50
24      IF(AFL.LE.0.35)GO TO 36
        IF(AFL.GT.0.35)GO TO 38
36      F=1.02
        GO TO 50
38      F=1.02+0.18*(AFL-0.35)
        GO TO 50
26      IF(AFL.LE.0.35)GO TO 40
        IF(AFL.GT.0.35)GO TO 42




40      F=1.04
        GO TO 50
42      F=1.04+0.2*(AFL-0.35)
        GO TO 50
27      IF(AFL.LE.0.35)GO TO 44
```

```
        GO TO 50
46      F=1.06+0.2*(AFL-0.35)
        GO TO 50
50      CD=0.848*F
        A=B*(H1MAX+P)
        VH=(Q1MAX/A)**2.0/(2.0*9.81)
        HEMX1=H1MAX+VH
        CV=(HEMX1/H1MAX)**U
        FK1=2.0/3.0
        FK2=(FK1*9.81)**0.5
        FU=1.0/U
        H1MAX=(Q1MAX/(CD*CV*FK1*FK2*B))**FU
111     CONTINUE
        H1MIN=(Q1MIN/(0.848*FK1*FK2*B))**U
        HLMAX=H1MAX/FL
        WRITE(*,*)'HLMAX=',HLMAX
        IF(HLMAX.GE.0.33)GO TO 106
        WRITE(6,48)
48      FORMAT(10X,'__________DESIGN PARAMETER______________')
106     WRITE(6,107)
107     FORMAT(10X,'THE AIR POCKET SHOUD BE FULLY AIRATED'/)
        P=Y1MAX-H1MAX
        WRITE(6,104)P,H1MAX,H1MIN
        WRITE(20,104)P,H1MAX,H1MIN
104     FORMAT(10X,'HEIGHT OF CREST ABOVE APPROACH CHANNEL BED P'/
     1  10X,'IN METERS'/
     1  10X,'DESIGN HEAD ABOVE CREST OF WEIR H1MAX IN METERS'/
     1  10X,'MINIMUM HEAD ABOVE CREST OF WEIR H1MIN IN METERS'/
     1  10X,' P='F10.4/10X,'H1MAX='F10.4/10X,'H1MIN='F10.4/)
        WRITE(6,105)
105     FORMAT(10X,'LIMIT OF APPLICATION OF BROAD CRESTED'/
     1  10X,'RECTANGULAR PROFILE WEIR'/
     1  10X,'H1MIN>0.06'/10X,'H1MAX/(H1MAX+P)<0.6'/
     1  10X,'P>0.15'/10X,'H1MAX/FL<1.5'/10X,'BM>0.3'/)
        IF(IANS.EQ.1)GO TO 346
        GO TO 347
346     WRITE(20,380)Q1MAX,Q1MIN,B,Y1MAX
        WRITE(20,48)
        WRITE(20,107)
        WRITE(20,104)P,H1MAX,H1MIN
        WRITE(20,105)
347     RETURN
        END
```

EXAMPLE 1
Q1MAX=MAXIMUM DISCHARGE IN CUBIC METERS/SEC
Q1MIN=MINIMUM DISCHARGE IN CUBIC METERS/SEC
B=WIDTH OF WEIR IN METERS
H1MAX=MAXIMUM HEAD IN METERS
FL=LENTGH ALONG FLOW DIRECTION
YD=DOWN STREAM Y COORDINATE PROFILE
OF WES-SPILLWAY METERS
YU=DOWN STREAM Y COORDINATE PROFILE
OF WES-SPILLWAY IN METERS

________INPUT DATA WES STANDARD WEIR______________
MAXIMUM DISCHARGE Q1MAX= 60.0000 CUBIC METERS
MINIMUM DISCHARGE Q1MIN= 6.0000 CUBIC METERS
BREATH OF WEIR B= 15.0000 METERS
MAXIMUM DEPTH OF WATER Y1MAX= 8.0000 METERS

__________DESIGN PARAMETER_____________
HEIGHT OF CREST ABOVE APPROACH CHANNEL BED P
DESIGN HEAD ABOVE CREST OF WEIR H1MAX
MINIMUM HEAD ABOVE CREST OF WEIR H1MIN
P= 7.0009 METERS
H1MAX= .9991 METERS
H1MIN= .3230 METERS

------- WEIR PROFILE-----------------

X=	.00000	YD=	.00000
X=	.10000	YD=	.00501
X=	.20000	YD=	.01805
X=	.30000	YD=	.03821
X=	.40000	YD=	.06506
X=	.50000	YD=	.09831
X=	.60000	YD=	.13775
X=	.70000	YD=	.18321
X=	.80000	YD=	.23455
X=	.90000	YD=	.29165
X=	1.00000	YD=	.35442
X=	1.10000	YD=	.42276
X=	1.20000	YD=	.49659
X=	1.30000	YD=	.57585
X=	1.40000	YD=	.66047
X=	1.50000	YD=	.75038
X=	1.60000	YD=	.84554
X=	1.70000	YD=	.94590
X=	1.80000	YD=	1.05140
X=	1.90000	YD=	1.16201
X=	2.00000	YD=	1.27767
X=	2.10000	YD=	1.39836
X=	2.20000	YD=	1.52404
X=	2.30000	YD=	1.65467
X=	2.40000	YD=	1.79021
X=	2.50000	YD=	1.93065
X=	2.60000	YD=	2.07594

X=	2.70000	YD=	2.22606
X=	2.80000	YD=	2.38098
X=	2.90000	YD=	2.54068
X=	3.00000	YD=	2.70513
X=	3.10000	YD=	2.87431
X=	3.20000	YD=	3.04819
X=	3.30000	YD=	3.22675
X=	3.40000	YD=	3.40997
X=	3.50000	YD=	3.59782
X=	3.60000	YD=	3.79030
X=	3.70000	YD=	3.98738
X=	3.80000	YD=	4.18903
X=	3.90000	YD=	4.39525
X=	4.00000	YD=	4.60601
X=	4.10000	YD=	4.82130
X=	4.20000	YD=	5.04110
X=	4.30000	YD=	5.26539
X=	4.40000	YD=	5.49416
X=	4.50000	YD=	5.72739
X=	4.60000	YD=	5.96507
X=	4.70000	YD=	6.20719
X=	4.80000	YD=	6.45372
X=	4.90000	YD=	6.70466
X=	5.00000	YD=	6.95999
X=	5.10000	YD=	7.21969
X=	.00000	YU=	-.00127
X=	-.10000	YU=	.00506
X=	-.20000	YU=	.02341
X=	-.30000	YU=	.05285
X=	-.40000	YU=	.09271
X=	-.50000	YU=	.14252
X=	-.60000	YU=	.20188
X=	-.70000	YU=	.27048
X=	-.80000	YU=	.34807
X=	-.90000	YU=	.43443

EXAMPLE 2

Q1MAX=MAXIMUM DISCHARGE IN CUBIC METERS/SEC
Q1MIN=MINIMUM DISCHARGE IN CUBIC METERS/SEC
B=WIDTH OF WEIR IN METERS
H1MAX=MAXIMUM HEAD IN METERS
K=PROPORTIONALITY PARAMETER
X=X COORDINATE OF PROPORTIONAL WEIR IN METERS
Y=Y COORDINATE OF PROPORTIONAL WEIR IN METERS

```
______INPUT DATA LINEAR PROPORTIONAL WEIR______________
Q1MAX=     .4000  Q1MIN= .1500  B=       .6000
Y1MAX=    1.0000  CD=     .6300  G=     9.8100
      __________DESIGN PARAMETER______________
A=      .2624  K=        .85761  H1MAX=        .55387  P=       .4461
```

------- WEIR PROFILE-----------------

Y=	.01000	X=	.26318
Y=	.02000	X=	.24855
Y=	.03000	X=	.23772
Y=	.04000	X=	.22890
Y=	.05000	X=	.22139
Y=	.06000	X=	.21481
Y=	.07000	X=	.20894
Y=	.08000	X=	.20364
Y=	.09000	X=	.19881
Y=	.10000	X=	.19437
Y=	.11000	X=	.19025
Y=	.12000	X=	.18643
Y=	.13000	X=	.18286
Y=	.14000	X=	.17951
Y=	.15000	X=	.17635
Y=	.16000	X=	.17338
Y=	.17000	X=	.17056
Y=	.18000	X=	.16788
Y=	.19000	X=	.16534
Y=	.20000	X=	.16292
Y=	.21000	X=	.16061
Y=	.22000	X=	.15840
Y=	.23000	X=	.15628
Y=	.24000	X=	.15425
Y=	.25000	X=	.15230
Y=	.26000	X=	.15043
Y=	.27000	X=	.14863
Y=	.28000	X=	.14689
Y=	.29000	X=	.14522
Y=	.30000	X=	.14360
Y=	.31000	X=	.14204
Y=	.32000	X=	.14053
Y=	.33000	X=	.13907
Y=	.34000	X=	.13766
Y=	.35000	X=	.13629
Y=	.36000	X=	.13496
Y=	.37000	X=	.13367
Y=	.38000	X=	.13241
Y=	.39000	X=	.13119
Y=	.40000	X=	.13001
Y=	.41000	X=	.12886
Y=	.42000	X=	.12774
Y=	.43000	X=	.12665
Y=	.44000	X=	.12558
Y=	.45000	X=	.12455
Y=	.46000	X=	.12354
Y=	.47000	X=	.12255
Y=	.48000	X=	.12159
Y=	.49000	X=	.12065
Y=	.50000	X=	.11973
Y=	.51000	X=	.11883
Y=	.52000	X=	.11795
Y=	.53000	X=	.11710
Y=	.54000	X=	.11626
Y=	.55000	X=	.11544

EXAMPLE 3
Q1MAX=MAXIMUM DISCHARGE IN CUBIC METERS/SEC
Q1MIN=MINIMUM DISCHARGE IN CUBIC METERS/SEC
B=WIDTH OF WEIR IN METERS
H1MAX=MAXIMUM HEAD IN METERS
K=PROPORTIONALITY PARAMETER
X=X COORDINATE OF PROPORTIONAL WEIR IN METERS
Y=Y COORDINATE OF PROPORTIONAL WEIR IN METERS

--- INPUT DATA LOGRITHMIC WEIR------------

Q1MAX= .1100 Q1MIN= .0500 B= .5000
Y1MAX= .4000 CD= .6300 G= 9.8100

__________DESIGN PARAMETER_____________

A= .2395 K= .08250 H1MAX= .52117 P= -.1212

------ WEIR PROFILE----------------

Y=	.05000	X=	.09823
Y=	.10000	X=	.06003
Y=	.15000	X=	.04002
Y=	.20000	X=	.02798
Y=	.25000	X=	.02016
Y=	.30000	X=	.01481
Y=	.35000	X=	.01101
Y=	.40000	X=	.00823
Y=	.45000	X=	.00614
Y=	.50000	X=	.00456
Y=	.55000	X=	.00333
Y=	.60000	X=	.00236
Y=	.65000	X=	.00159
Y=	.70000	X=	.00098
Y=	.75000	X=	.00049
Y=	.80000	X=	.00008